The Bequest of William Taylor, Esq. of Boston, &c. July 2d 1838.

Mathematical
ELEMENTS
OF
Natural Philoſophy,
Confirm'd by EXPERIMENTS;
OR, AN
INTRODUCTION
TO
Sir ISAAC NEWTON's Philoſophy.

VOL. II.

Written in LATIN
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TO THE

Moſt Noble and Right Honourable

THOMAS

Lord *PARKER*,

Baron of *Macclesfield*,

Lord HIGH CHANCELLOR
of *Great Britain*, &c.

My LORD,

IF whilſt Your Lordſhip's Hours are taken up with an Employment of the greateſt Fatigue as well as the higheſt Honour, there can be any Time allowed for Recreation, your

Lordſhip makes that your Diverſion, which few can attain to without painful Application and laborious Study. To become a skilful Mathematician and a ſound Philoſopher, and at the ſame Time ſhine in other Parts of Learning, requires a great and extenſive Genius: But to lead a Life of Buſineſs, and be eminent in the Law, where Reputation is only got by conſtant Practice, as well as Brightneſs of Parts; and yet, in thoſe few Minutes of Leiſure that are allowed to breathe in, and are, as it were, ſtolen from Sleep, to play with all the Intricacies of Lines and Numbers, to view and underſtand the Syſtem of the World, the Proportion, Symmetry, and Harmony of its ſeveral Parts; to be acquainted with all the Experiments of Conſequence that have been made, and be able to contrive new ones as uſeful as inſtructive; was only reſerved

ſerved to Men of uncommon Capacities, and to none in ſo eminent a Degree as to your Lordſhip.

THE Honour I have had of being admitted into your Lordſhip's Converſation, has given me an Opportunity to know which of the Mathematical Sciences are chiefly lik'd by you: And as *Aſtronomy* and *Optics* ſeem to have the Preference, I thought this Tranſlation of Dr. 'sGRAVESANDE'S Second Volume would not be unacceptable.

HERE you have the Principles of the common Optics reduced into a ſmall Compaſs, and confirmed by new Experiments of the Author's own Invention: A fine Application of the Action of Electric Bodies to diſcover the Nature of Fire: And Sir ISAAC NEWTON'S Doctrine of *Light* and *Colours*

proved by the moſt conſiderable of his Experiments, which Dr. *'s Graveſande* performs with an Apparatus very ingeniouſly contrived, and nicely expreſſed by curious Figures. The laſt Part of this Volume not only leads a Beginner gradually on from the moſt ſimple to underſtand the moſt difficult *Phænomena* of *Aſtronomy*; but gives ſuch a phyſical Account of the Celeſtial Motions as muſt be fully ſatisfactory to the beſt Geometricians. There your Lordſhip will ſee with Pleaſure, that there are Profeſſors abroad who underſtand the PRINCIPIA; and have ſo juſt a Value for that excellent Book, as to take Pains to propagate the wonderful Truths which it demonſtrates, ſo as to make them plain to ſuch Philoſophers as are not yet able to go through all the difficult Propoſitions from whence they are deduced. But I will detain your Lordſhip

ſhip no longer, either from the important Buſineſs of your Station, or the pleaſing Truths of the Author, than while I beg Leave to ſubſcribe myſelf,

My LORD,

Your Lordſhip's

Moſt Obliged,

Moſt Obedient, and

Moſt Humble Servant,

J. T. DESAGULIERS.

ship no longer, either from the important Bulinels of your Station, or the pleafing Truths of the Author, than while I beg Leave to fubfcribe myfelf,

My LORD,

Your Lordfhip's

The AUTHOR's PREFACE.



Spoke of the Method of Reaſoning to be uſed in Natural Philoſophy, in the firſt Chapter of the firſt Volume, and in the Preface endeavoured to vindicate the Goodneſs of the Method I have followed. There are ſeveral remarkable Specimens of this Method in the preſent Volume, which evidently ſhew Sir ISAAC NEWTON's *great Superiority of Genius above all other Philoſophers.*

Before him, Naturaliſts were in the Dark in numberleſs Things relating to Light, and eſpecially to Colours. For Inſtance, whoever ſuſpected before, that the Opacity of Bodies depended upon their Interſtices, ſo that a Body becomes tranſparent, when theſe Interſtices are filled with a Medium of the ſame Denſity as the Particles of the Body itſelf.

His

His Account of the Planetary Syſtem, and particularly of the Motion of the Moon, is not leſs worthy of eternal Praiſes, being likely to carry Aſtronomy to a greater Pitch of Perfection than the niceſt Obſervations alone could poſſibly do. For if a Man is acquainted with the Laws that govern the Syſtem of the World, he will be able to make a better Uſe of his Obſervations, and to compute the Motions of the heavenly Bodies more exactly than if he had nothing but Obſervations to direct him.

It was my Deſign in theſe two Books, to give my Reader a general Notion of the chief Things diſcovered by Sir Isaac Newton *in Natural Philoſophy, and thereby to encourage him to the Study of the more abſtruſe, and, at the ſame Time, more ſublime Parts of Mathematics, after he has learned the firſt Principles of Geometry, to fit him for the reading of theſe plain Elements. He will, as it were, go to the Fountain Head, when he reads the Writings of our great Philoſopher, which will reveal ſuch Things to him, as were unknown to the profoundeſt Philoſophers before him; and which, though publiſhed, are ſtill a Secret to all but thorough Mathematicians.*

I have only a few Words more to ſay to the Engliſh Reader, concerning the two Engliſh Tranſlations of this Work.

As tedious and diſtaſteful as an Author's Complaints generally prove, they cannot, however, be diſallowed, when they are grounded upon ſuch an Injury done to the Author, as it is his Reader's Intereſt to be informed of.

Soon after the Publication of the firſt Volume of theſe Elements, *it was tranſlated into* Engliſh, *and print-*

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ed in London, *with the Name of a Celebrated Profeſſor of Mathematics, eminent for his Writings, inſcribed on the Title Page, as if he had looked over and corrected this Tranſlation. But whoever examines any one Page in the Book, will immediately diſcover the Wrong done to that Learned Gentleman, and the Abuſe made of his Name; ſince he will every where perceive manifeſt Signs of the Tranſlator's Ignorance of the very Principles of Phyſics and Mathematics, not to mention his Negligence with regard to the correcting of the Additions at the End of the Book, to the Numbers in the Margin, and the Diſtinction of the Propoſitions.*

Dr. DESAGULIERS, *whoſe Knowledge of Philoſophy, and Skill in making Experiments, are ſo well known, began to tranſlate the ſame Work about the ſame Time as the other, or rather before. But this obliging him to make more than ordinary Haſte, he could not himſelf wholly avoid the uſual Conſequences of too much Precipitation,* &c.

THE CONTENTS OF THE Second VOLUME.

BOOK III.

PART I. Concerning FIRE.

Chap. I. OF the Properties of Fire in general. Page 1.

Chap. II. That Fire adheres to Bodies, and is contained in them; where we ſhall alſo ſpeak of Electricity. p. 2.

Chap. III. Concerning the Motion of Fire, where we ſhall ſpeak of Heat and Light. p. 13.

Chap. IV. Of the Dilitation occaſioned by Heat. p. 18.

BOOK III.

PART II. Concerning the Inflection, Refraction and Reflection of Light.

Chap. V. Concerning the Inflection of the Rays of Light. p. 26.

Chap. VI.

Chap. VI. *Concerning the Refraction of Light, and its Laws.* Page. 26.
Chap. VII. *Of the Refraction of Light, when Mediums are ſeparated by a plane Surface.* p. 39.
Chap. VIII. *Concerning the Refraction of Light, when a ſpherical Surface ſeparates the Mediums.* p. 44.
Chap. IX. *Concerning the Motion of Light through a more denſe Medium. Where we ſhall take Notice of the Properties of Lenſes.* p. 53.
Chap. X. *Of Viſion; where we ſhall ſpeak of the Make of the Eye.* p. 58.
Chap. XI. *Of Viſion through Glaſſes, and how to correct ſome Defects of the Eyes.* p. 67.
Chap. XII. *Of Microſcopes and Teleſcopes.* p. 73.
Chap. XIII. *Of the Reflection of Light.* p. 80.
Chap. XIV. *Of plane Mirrors.* p. 87.
Chap. XV. *Of ſpherical Mirrors.* p. 88.
Chap. XVI. *Of the Magic Lantern.* p. 98.

BOOK III.

PART III. Of Opacity and Colours.

Chap. XVII. *Of the Opacity of Bodies.* p. 104.
Chap. XVIII. *Concerning the different Refrangibility of the Sun's Rays.* p. 108.
Chap. XIX. *Concerning the Colours of the Rays, and their Unchangeableneſs.* p. 116.
Chap. XX. *Of the Mixture of Colours, where we ſhall ſpeak of Whiteneſs.* p. 123.
Chap. XXI. *Of the Rainbow.* p. 127.
Chap. XXII. *Of the Colours of thin Plates.* p. 136.
Chap. XXIII. *Concerning the Colours of Natural Bodies.* p. 142.

The CONTENTS.

BOOK IV.

PART I. Of the Syſtem of the World.

Chap. I. *A general Idea of the Planetary Syſtem.* Page 149.
Chap. II. *Concerning the apparent Motion.* p. 160.
Chap. III. *Of the Phænomena or Appearances of the Sun from the Motion of the Earth in its Orbit.* p. 164.
Chap. IV. *Of the Phænomena of the inferior Planets, ariſing from the Earth's and their own Motions in their Orbits.* p. 167.
Chap. V. *Concerning the Phænomena of the ſuperior Planets, ariſing from their Motions and the Motions of the Earth in their reſpective Orbits.* p. 171.
Chap. VI. *Concerning the Phænomena of the Satellites, from their Motions in their Orbits. Where we ſhall ſpeak of the Eclipſes of the Sun and Moon* 173.
Chap. VII. *Of the Phænomena ariſing from the Motion of the Sun, the Planets, and the Moon about their Axes.* p. 180.
Chap. VIII. *Of the Phænomena which relate to the Surface of the Earth, and its particular Parts.* p. 185.
Chap. IX. *Concerning the Phænomena ariſing from the Motion of the Axis of the Earth.* p 200.
Chap. X. *Concerning the fixed Stars.* p. 201.

BOOK IV.

PART II. The Phyſical Cauſes of the Celeſtial Motions.

Chap. IX. *Concerning univerſal Gravity.* p. 206.

Chap.

The CONTENTS.

Chap. XII. *Of the Celestial Matter; where a* Vacuum *is proved.* Page 216.
Chap. XIII. *Concerning the Motion of the Earth,* p. 221.
Chap. XIV. *Concerning the Density of the Planets.* p. 227.
Chap. XV. *The Physical Explanation of the whole Planetary System.* p. 233.
Chap. XVI. *The Physical Explication of the Moon's Motion.* p 241.
Chap. XVII. *Concerning the Figures of the Planets.* p. 263.
Chap. XVIII. *The Physical Explanation of the Motion of the Axis of the Earth.* p 270.
Chap. XIX. *Concerning the Tides.* p 272.
Chap. XX. *Of the Moon's Density and Figure.* p. 281.

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Mathematical ELEMENTS OF *Natural Philoſophy*, Confirm'd by EXPERIMENTS.

VOL. II. BOOK III.

PART I. *Concerning FIRE.*

CHAP. I.

Of the Properties of Fire in general.



THO we know ſeveral Properties of Fire, yet we are ignorant of a great many things relating to it.

I ſhall not invent Hypotheſes, but reaſon from Experiments, and leave untouched what is not fully known.

Fire eaſily penetrates thro' all Bodies, however denſe and hard they are. For we have never yet known 544

any Body, that by the Application of Fire has not been heated in all its Points; that is, in every Part.

545 *Fire moves very ſwiftly*, as appears from Aſtronomical Obſervations.

546 *Fire unites itſelf to Bodies*; for when they are brought to the Fire, they grow hot, as we ſaid
547 before; *and in that Caſe they expand or ſwell:* Which Expanſion is alſo obſerved in ſuch Bodies,
548 whoſe Parts do not cohere, in which Caſe *they alſo acquire a great Degree of Elaſticity*, as is obſerved in Air and Vapours.

549 That *Fire is attracted by Bodies at a certain Diſtance from them*, will be ſhewn in the following
* 611 Part of this Book. *

If any Bodies are violently moved againſt one another, they will grow hot by ſuch a Friction, and that to a great Degree; which ſhews that
550 *all Bodies contain Fire in them:* for, by rubbing, Fire may be put in Motion, and ſeparated from Body, but can by no means be generated that way.

Having laid down theſe general Heads, we muſt examine ſeveral Things more particularly.

CHAP. II.

That Fire adherers to Bodies, and is contain'd in them; where we ſhall alſo ſpeak of Electricity.

AS we have already ſaid, one may prove that Fire is contain'd in all Bodies, becauſe there are no Bodies but what may be heat-
* 550 ed by Attrition; * and that it coheres firmly with the Parts of Bodies, appears in Smoke and Vapours: for Smoke and Vapours are made up of Parts ſeparated from Bodies, and agitated (ſome-

times very violently) by the Fire that is join'd with them.

There are, beſides, ſeveral remarkable Phænomena ariſing from Fire, contained in Bodies, ſome of which we ſhall here mention; amongſt which, there are ſuch as relate very much to Electricity, for which Reaſon, we muſt alſo treat of the Phænomena of Electricity.

DEFINITION.

Electricity *is that Property of Bodies, by which* 551
(when they are heated by Attrition) they attract, and repel lighter Bodies at a ſenſible Diſtance.

Experiment 1.] Take two Pieces of Rock 552
Cryſtal and rub them together, and immediately they will appear luminous all over, tho' they do not acquire any ſenſible Heat by that Attrition. Light (as well as Heat) is a Proof that there is Fire in a Body. The greateſt Light is in thoſe Points, where the Bodies touch one another.

Experiment 2.] Take a Glaſs Tube 15 or 18 553
Inches long, and one Inch in Diameter, and rub it with a Linnen or Woollen Cloth, and it will emit Light in the Dark.

Experiment 3. *Plate* I. *Fig.* 1.] This Tube, 554
heated by rubbing, has a very ſenſible Electricity; for if light Bodies, ſuch as Pieces of leaf Gold, and Soot, be laid upon a Plane, and the Tube be brought near them, they will be put in Motion, attracted, repelled, and driven ſeveral Ways by the Tube. The Tube acts at different Diſtances, according to the different State of the Air; ſometimes at the Diſtance of one Foot; when the Air is full of Vapours the Effect is diminiſhed.

555 There is one Thing remarkable, and very hard to explain in this Experiment, concerning the Direction of the Attrition; when you rub the Tube, one End of it his held in one Hand, whilſt it is rubb'd with the other; which, if it be done from the Hand that holds towards the other End of the Tube, the Effect will not be ſenſible; but if you rub from the free End of the Tube towards the End held in the Hand, the contrary will happen. And this happens indifferently, whether you hold the open or the ſhut End of the Tube in your Hand.

556 In the following Experiments (*Plate* I. *Fig.* 2.) Glaſs Globes are ſwiftly whirl'd about; to perform which, there muſt be a cylindric Neck at each End of every Globe; but only one of theſe Necks is to be open, and both are to have Braſs Ferrels, ſuch as are repreſented at G; a Cock E muſt be ſcrew'd on to the Ferrel at the open Neck, and the oppoſite Braſs Ferrel muſt have a little Wheel *r* of about an Inch and a half Diameter, join'd to it, with a ſmall Braſs Axis ſtanding out: There is juſt ſuch another Piece of Braſs ſcrew'd on to the Cock, ſo that it may be taken on and off at Pleaſure. Theſe Axes go about a Quarter of an Inch into the Pillars S S, that ſupport the Globe, and are Centers for it to whirl upon when it turns about its Axis.

The Pillars S S ſtand upon a ſtrong horizontal Board of about an Inch and a half thick, framed into three other Boards, as may be ſeen in the Figure: In that which ſtands foreright, there is an Hole *f* that you may come at the lower Part of the Pillar, to make it faſt with a Nut or Screw. The other Pillar S is likewiſe faſten'd by a Screw applied under the horizontal Board, and moved forwards and backwards in a Slit of 4 or 5 Inches long, before it be made faſt, in order to take the

Glaſs Globes in and out, and to take in ſuch as are larger or ſmaller than others, according to the different Experiments to be made.

There is a great Wheel R which is turn'd round by means of the Handle M, and thereby gives a very ſwift whirling Motion to the Globe G.

In the Side of the upper Board, there is a Slit, along which the Pully *t* may be moved, by means of the Screw *c*, in order to keep ſtretch'd the Rope that goes round the Wheels R and *r*.

Experiment 4 & 5. *Plate* II. *Fig.* 1.] Apply a 557
Glaſs Globe of about 8 or 9 Inches Diameter, to the Machine above-mention'd, and let it be briskly whirl'd in a dark Place, the Hand all the while being held againſt it, to give it Attrition.

If the Globe be exhauſted of its Air, it will appear all luminous within, but moſtly ſo where the Hand touches the Glaſs.

But if the Globe has Air in it, and being 558
whirl'd in the ſame Manner, the Hand be applied to it, no Light appears, either in the inner or outer Surface of the Glaſs; but Bodies at a ſmall Diſtance from the Glaſs (as for Example, at a Quarter of an Inch, or nearer) become luminous; and ſo only thoſe Parts of the Hand held againſt the Glaſs, which terminate, or rather environ the Parts that immediately touch the Globe, are luminous.

Experiment 6. *Plate* I. *Fig.* 2.] Take the Globe 559
made uſe of in the foregoing Experiments, and put it in between the Pillars, to whirl it as before: Then take a Braſs Wire *a b d*, circularly bent in the upper Part, and fix it ſo that its curve Part may be about 4 Inches off of the Globe, with ſmall Threads hanging from it, which being extended towards the Center of the Globe

come within a quarter of an Inch of the Surface of the Globe.

Whirl the Globe and apply the Hand, and immediately the Threads will be moved irregularly by the Agitation of the Air; but when the Glaſs is heated by the Attrition, all the Threads are directed towards the Center of the Globe, as may be ſeen in the Figure: And if the Hand be applied a little on one Side, or nearer the Pole of the Globe, the Threads will be directed towards that Point of the Axis which is under the Hand.

560 If the Air be drawn out of the Globe, this whole Effect ceaſes.

561 *Experiment* 7. *Plate* I. *Fig.* 3.] Take another Globe like the former; only differing in this, that the open'd Neck muſt have a larger Opening than that of the Globe G, ſo that you may put into it a round flat Piece of Wood *o*, that has a Braſs Wire for its Axis. In order to fix this Piece of Wood in the Middle of the Globe, its Axis muſt be firmly ſcrew'd to the Middle of the Cover that is join'd to the open Neck of the Globe at *b*: and the Cock E is alſo join'd to the Middle of the Cover on the outſide.

To the wooden Circle ſmall Threads are faſten'd, which, being extended, almoſt touch the inner Surface of the Globe.

Turn the great Wheel ſo as to whirl the Globe, and rub it till it becomes warm, as was done in the former Experiments; if you ceaſe to whirl the Globe, and the Hand be taken off, the Threads will immediately ſtretch themſelves out like Radii from the Center towards the Surface of the Globe, yet they hardly remain one Moment at reſt; for tho the Globe be exactly ſhut, theſe Threads will be put in Motion, as

appears

appears by blowing againſt the Globe, tho you ſtand two Foot off, or farther, from the Globe. If you bring your Finger towards the Globe, tho you do not touch it, the Threads next to it will be attracted by the Finger, and directed towards it; nay, and ſometimes they fly from it. If you apply the whole Hand to the Globe, the Threads will be mov'd violently and irregularly.

And if all the Air be drawn out, as in the foregoing Experiment, the whole Effect ceaſes; and the Threads (both before and after the Friction) only hang down by their Gravity. 562

If we attend to all the foregoing Experiments, the following Concluſions ſeem to be naturally deduced from them, which we do not give out as certain, but very probable; for we muſt always diſtinguiſh Certainty from Probability.

*That Glaſs contains in it, and has, about its Surface, a certain Atmoſphere, which is excited by Friction, * and put into a vibratory Motion*; for it attracts and repels light Bodies; *the ſmalleſt Parts of the Glaſs are agitated by the Attrition, and by reaſon of their Elaſticity, their Motion is vibratory, which is communicated to the Atmoſphere above-mention'd; and therefore that Atmoſphere exerts its Action the farther, the greater Agitation the Parts of the Glaſs receive when a greater Attrition is given to the Glaſs. 563 * 554, 559, 561. * 554.

The Fire, contained in the Glaſs, is expell'd by the Action of this Atmoſphere; at leaſt it is mov'd with it. For when light Bodies are put in Motion at a Diſtance from the Glaſs the Bodies alſo beeome lucid at a Diſtance. * 564 * 559, 558.

It is plain, that *this Atmoſphere and Fire is more eaſily mov'd in a Place void of Air:* For if the Globe be exhauſted of its Air, there can be perceiv'd no Light, nor any Effect of Electricity on the outſide of the Globe *, but the inſide of the Globe 565 * 557, 560.

Globe appears very luminous, and this Fire is perceiv'd to be in greater Quantity in this Experiment, than in that immediately after men-
* 558 tion'd *.

But the Action of the Electricity does alſo
* 562 ceaſe on the Inſide when the Air is drawn out *, which ſeems to overthrow what we ſaid of the more eaſy Motion of the Atmoſphere of Glaſs *in Vacuo:* But yet it is not probable that it ſhou'd move no whither in this Caſe. On the contrary, it ſeems to go the ſame Way as the Fire, and to move that way where there is the leaſt Reſiſtance; and that the ceaſing of the Action of Electricity is to be attributed to the Want of Air,
566 by means of which, *the Threads are moved by the*
* 605 *Atmoſphere*; as we ſhall hereafter ſhew *; and the
* 607 Fire, which freely penetrates all Bodies, acts upon them violently *by means of the Air* or Vapour.

But laying aſide Conjectures, tho they have a great many Experiments for their Foundation, let us return to other Things relating to Fire; as ſeveral Experiments are to be made *in Vacuo*, we muſt deſcribe the following *Machine* contriv'd to give Attrition to Bodies *in Vacuo*.

567 *Plate* II. *Fig.* 2.] Ler M be the Air-Pump de-
* 437 ſcrib'd before *, L L the Braſs Plate of the Pump on which the Glaſs Receivers are ſet; on each Side of the Plate there is a wooden Pillar, A D, A D, which Pillars ſtand on the Board that carries the Air-Pump Plate, having their Baſe upon it, and a Part below the Baſe, and going thro' the Board with an Hole in it, to receive two croſs Pieces of Wood or Wedges, that make them faſt during the Experiment, but ſo that the ſaid Pillars may be taken away afterwards.

The Glaſs Receiver, in which the Experiments are to be made, is about 9 Inches high, and 6 in

in Diameter, with a Cover * that has annex'd to * 440
it a Box or Collar full of oil'd Leathers thro' which a Braſs Axis paſſes; and leſt in the whirling round of the Axis the lower End ſhou'd move, Part of the Box is made ſquare, ſo as exactly to fit a ſquare Hole in the Horizontal Board E E that preſſes on the Cover, and is made faſt by bringing down the Nuts or Screws B B at each End, without bearing upon the Shoulders of the Pillars.

Towards the upper Part of the Pillars, there is a narrower horizontal Board F F preſs'd down alſo and faſtened with Nuts, which has fix'd to it, on the under Side, a Piece of Braſs *g*, with an Hole in it for the upper End of the above-mentioned Axis to turn in, whilſt the biggeſt Part of this Axis, being in the middle of the Glaſs, has an outſide Screw upon it, with the two Wing-Nuts *d*, *d*, moveable upon it, in order to faſten ſeveral Bodies upon the Axis.

The lower End of the Axis turns in the Hole *c*. The Braſs Spring *f f* is joined to the Piece *c*, which ſcrews it down to the Air-Pump Plate at the Hole where the Air is drawn out; but there muſt always be made a ſmall Hole or Paſſage in the Piece *c*, for the Air to be drawn out at.

Having exhauſted the Receiver, the Axis above-mentioned (by reaſon of the oiled Leathers in the Collar P) may be turned round without admitting any Air; but to give it a quick Motion, there is a little Braſs Wheel *r* of about 2 Inches Diameter, with Points in its Groove, that the Rope, that turns it round, may not ſlip.

The great Wheel R, of about 3 Foot Diameter with its Frame, is brought up cloſe to the Air-Pump, and made faſt to its Foot by a Screw.

The Rope, that goes about the leſſer Wheel *r*, is brought down over Pullies obliquely placed in

in the upper Part of the Pillars C, C, and being over them, comes down to the great Wheel which it goes round; ſo that by turning the vertical Wheel R, the Braſs Axis, above deſcribed, is carried round very ſwiftly, whereby a Motion is communicated to Bodies *in Vacuo* for ſeveral Experiments.

586 *Experiment* 8.] Take a Glaſs Globe of three Inches Diameter, or of two Inches and a half Diameter, with an Hole on each Side, where it may alſo have cylindric Necks. The Axis above-mention'd muſt go thro' thoſe Holes, in order to give the Globe a whirling Motion; Pieces of Cork muſt be put on each Side of the Globe to cover its Holes, and made faſt with the Nuts *d*, *d*, in the Manner that they appear in the Figure, to hold faſt together the Plates or little Wheels, thro' which the Axis goes.

This Globe, thus fix'd, will be ſwiftly mov'd *in Vacuo* with its Axis, by turning the Wheel R: To cauſe Attrition, a Piece of Woollen Cloth muſt be tied on to each Side of the Braſs Spring *f*, *f*, which by its Elaſticity preſſes the Globe hard on each Side.

Making the Experiment in the dark, the Globe will appear luminous; and if the Motion be continued till the Globe grows hot by the Attrition, the Light will indeed be increaſed, but will appear fix'd in the Places where the Attrition is made.

569 It follows from that Experiment, that *the Fire, contained in Glaſs, does not want Air to make it viſible*, for it grows hot, and ſhines when both the internal and external Air are taken out.

570 *Experiment* 9.] Take a round Piece of Wood of 2, or 2 $\frac{1}{2}$ Inches Diameter, and about $\frac{1}{4}$ an Inch

Inch thick, and let it have ſeveral Hollows cut in its Edge, that it may be encompaſs'd round with Beads of Plaiſter, which may be made faſt to it with Threads going thro' them. Let this Piece of Wood, thus prepar'd, be made faſt upon the Axis above-mention'd, in the ſame Manner as the little Globe had been faſten'd; then give Attrition *in Vacuo*, as in that Experiment, and Light will be thereby produced in the dark.

Experiment 10.] That Quickſilver contains Fire is plain, from Experiments made upon it, *in Vacuo*. For if Mercury well clean'd be ſhak'd about in an exhauſted Glaſs, it will appear luminous. 571

If you put Mercury into a Glaſs Globe, the Globe may be whirl'd round, as in the former Experiments, which will be delightful to ſee, if the Glaſs be mov'd ſlowly. If Mercury has no Tin mix'd with it, it may be clean'd with boiling hot Vinegar. 572

The Globe, that has the Mercury in it, may be exhauſted by ſcrewing on to it a Pipe about 2 Foot long, the lower End of which muſt be ſcrew'd on to the Hole in the Middle of the Plate of the Air-Pump. 573

Then, if you cover both that Hole and the Hole thro' which the Air is drawn out with one of the Receivers above-mention'd, the Air will be eaſily drawn out of the Globe.

Plate I. *Fig.* 4.] Take a Plate O, and having ſcrew'd on to it the Pipe E E, whoſe other End is ſcrew'd to the Air-Pump, put the Glaſs Receiver R upon it, and pump out the Air from it. The Pipe, thro' which the Air is drawn out, muſt ſtand up beyond the Plate in the Receiver about 4 or 5 Inches, be bent, and have a ſmall Hole in it; which muſt be taken 574

ken care of, for fear any Mercury ſhou'd get into the Air-Pump.

The middle of this Plate, has a Braſs Pipe B; whoſe lower End, that is without an Hole, comes down almoſt to the Bottom of the Veſſel V, that contains very clean Mercury: There is an Hole in the Side of the Pipe, exactly ſhut by the Pin A. The upper End of this Pipe has a very ſmall Hole in it, and comes up thro' the Plate into the Receiver.

The Height of the Receiver R is about 16 Inches, and its Diameter 4 Inches; pump the Air out of it, and then open the Hole in the Side of the Pipe B, and the Mercury by the Preſſure of the external Air will go up to the Tube, and will ſpout very ſtrongly into the Receiver, ſtriking againſt the Top of it.

The Experiment muſt be made in a dark Place, and the Mercury will appear luminous.

575 *Experiment* 11.] Chymiſts make a certain Preparation of Urine, which they call *Phoſphorus of Urine*; which muſt be kept in Water. If it be roll'd up into ſmall cylindrical Pieces like a Pencil, and you write with it upon a Paper, when you hold the Paper in a dark Place, you will ſee Letters of Fire. The *Phoſphorus* itſelf, when you take it out of the Water, will grow hot and ſmoke; all which ſhews that the *Phoſphorus* contains a great deal of Fire.

576 In this Experiment, *we may obſerve that Water acts upon the Fire contain'd in the* Phoſphorus; for *it keeps it in*, ſo that it cannot get out ſo long as the Phoſphorus is cover'd with Water; but as ſoon as the Water is taken away, the Heat and Smoke immediately ſhew that the Fire iſſues

577 out of the Phoſphorus. *The Air* alſo *does, in ſome meaſure, keep in the Fire contain'd in hot Water*; that

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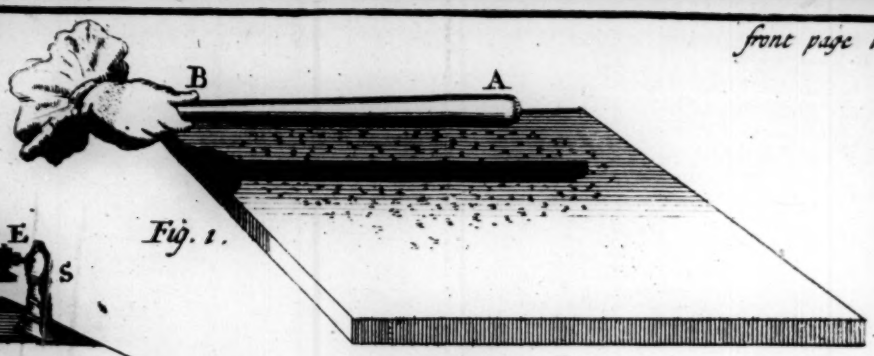


Fig. 1.

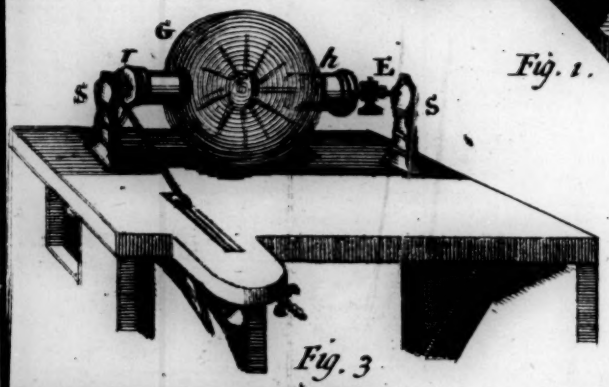


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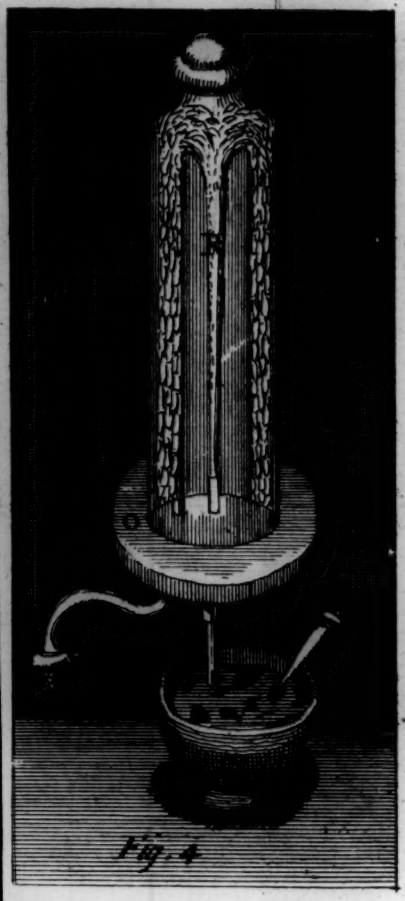


Fig. 4

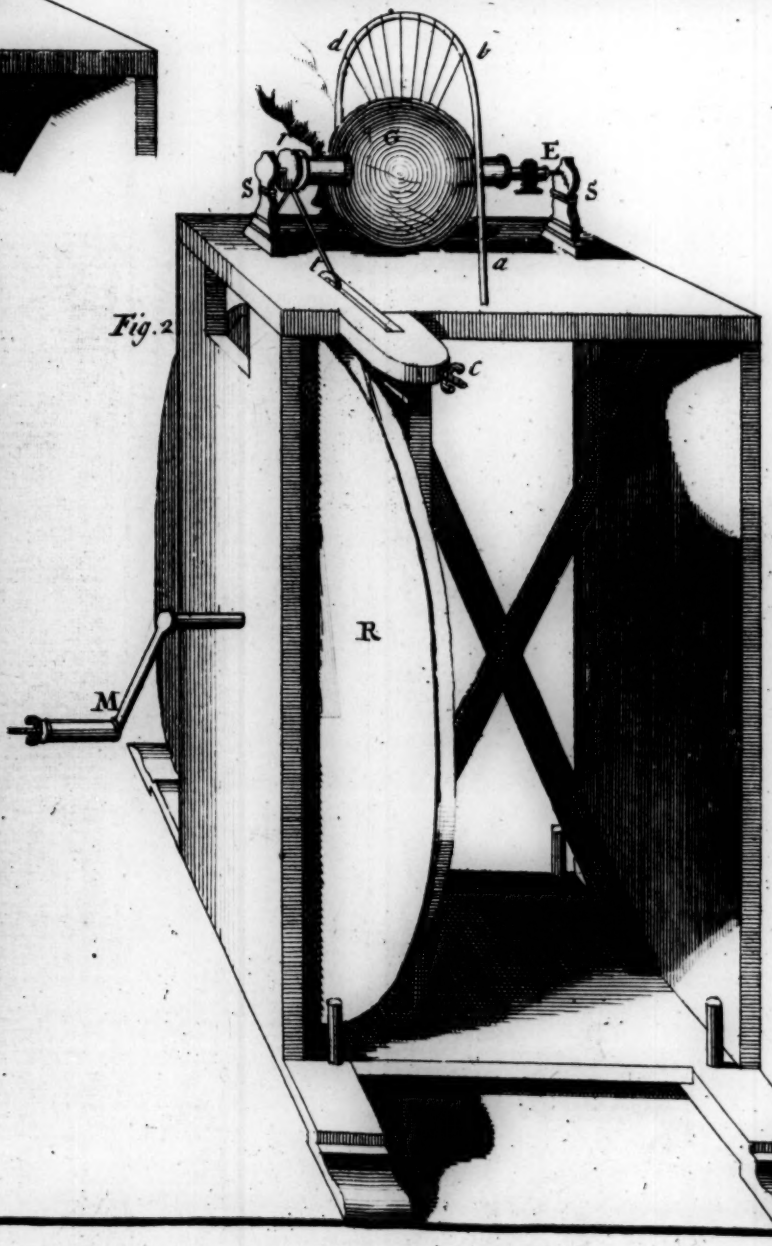
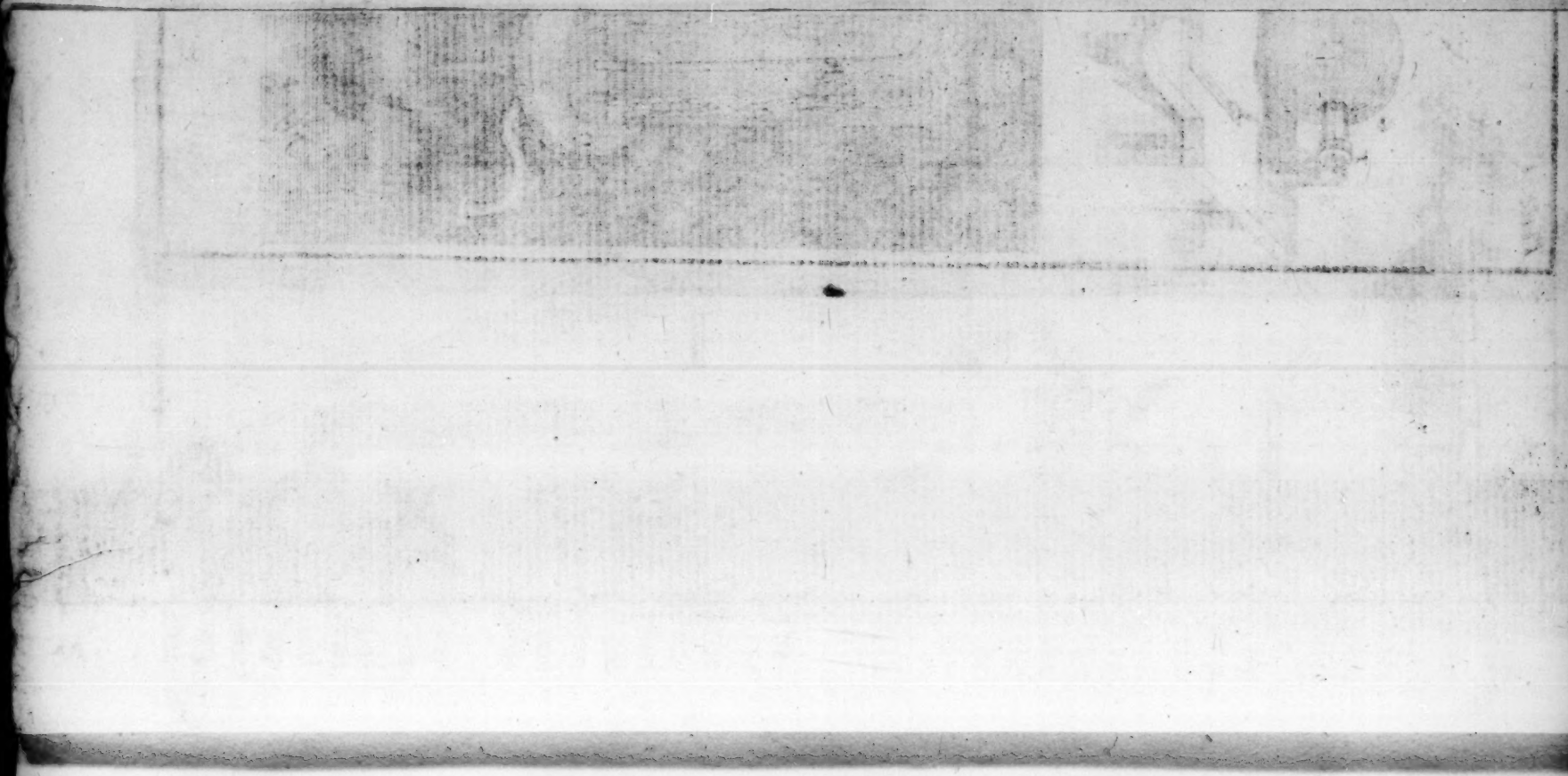


Fig. 2



that is, hinders it from going out of it ſo faſt as it will do *in Vacuo.*

Experiment 12.] Take two Veſſels that are equal and alike, and put an equal Quantity of boiling Water into each of them. Let one of them be ſet upon the Air-Pump Plate under a Receiver, and pump out the Air; when you are pumping, the Water boils violently by the Action of the Fire that goes out of it; and then ſoon becomes only lukewarm, whilſt the Water in the other Veſſel, which remain'd in the open Air, has ſcarce loſt any of its Heat.

One may obſerve ſomething like this in ſhi- 578
ning Wood; for ſome Wood that is rotted in the Ground, ſhines when it is taken out; the Earth that encompaſs'd the Wood kept in the Fire, which goes out when that is remov'd, and the Wood continues to ſhine for ſome Days. In an exhauſted Receiver, the Light is ſoon deſtroy'd, and is not reſtor'd by the Re-admiſſion of the Air.

But it cannot be eaſily determin'd how Fire is confined in a Body by the ambient Bodies, nor is it eaſy to find out what Action produces this Effect; it is hardly probable that Preſſure is here much concerned, ſince Fire does eaſily penetrate all Bodies by its Subtilty.

CHAP. III.

Concerning the Motion of Fire, where we ſhall ſpeak of Heat and Light.

WE have ſaid that Fire moves very ſwiftly *, and this Motion, in different Cir- * 545
cumſtances, produces different Effects. Heat and Light

Light are to be attributed to the different Mo-
579 tions of Fire. *Heat, in a hot Body, is the Agitation of the Parts of the Body and the Fire contained in it,* by which Agitation, a Motion is produced in our Bodies, which excites the Idea of Heat
580 in our Mind. *Heat, in reſpect of us, is nothing but that Idea, and in the hot Body is nothing but Motion.* Here we muſt call to mind what has been ſaid of the Senſations in general (N. 502.) which alſo may be referr'd to Light.

581 *When Fire enters our Eyes in Right Lines, by the Motion that it communicates to the* Fibres *in the Bottom of the Eye, it excites the Idea of Light*; of which Motion of the Fibres we ſhall ſpeak more
* 716 particularly hereafter. * *A rectilinear Motion* is
582 the Motion of Light, as it appears from its being eaſily ſtopped by an Obſtacle. On the contrary, ſuch a Motion *is not requir'd in Heat:* and that *an irregular Motion is more for it,* may be proved, becauſe the Rays, that come directly from the Sun to the Top of a Mountain, produce no ſenſible Heat; whilſt in the Valley, where the Rays are agitated with an irregular Motion by ſeveral Reflexions, there is often produced a very intenſe Heat.

Definition.

A Body *is ſaid to be* Lucid, *when it emits Light,* that is, when it gives Fire a Motion in right Lines.

583 That *there is not always Light, where there is Fire,* is beyond all doubt; for we daily ſee hot Bodies that do not ſhine.

584 But *whether there be any Body without Heat, cannot be determin'd.* Heat, in all Bodies, is a Motion that may be infinitely diminiſh'd; and there may be ſuch a Motion, tho it be not ſenſible to us, becauſe often we cannot diſcover any

any thing of Heat; for certainly there are a great many lucid Bodies, in which we can perceive no ſenſible Heat.* Concerning which it may be obſerv'd, that no Heat is ſenſible to us, unleſs the Body, that acts upon our Organs of Senſe, has a greater Degree of Heat than that of our Organs. Which ſhews us, that the Judgment of our Senſes, concerning Heat, is wholly uncertain. * 571

When the ſmalleſt Parts of which any Body is made up are agitated, either by Attrition, or the Action of Fire applied externally to it, or any other Way; the Fire is ſeparated from the ſmall Particles and agitated in the Body; then alſo the Fire and the Particles of the Body act upon one another by their Attraction, as is prov'd by the Experiments which we ſhall hereafter mention.* By this Action ſome Parts are ſeparated from the Body, and carried off from it by the Motion of the Fire. And this is the Cauſe why *hard Bodies are often ſet on Fire by a violent Attrition.* * 611 585

Hence we deduce, that *the burning of Bodies is a Separation of their Parts by the mutual Action of the Fire, and thoſe Parts on each other*; ſome of *thoſe Parts, carried off by the Motion of the Fire, make Flame and Smoke.* 586 587

We ſee beſides, that a Body, that is burn'd by the Application of Fire, is not only diſſolv'd by the Action of the external Fire, but alſo by the Action of the Fire contained in the Body itſelf; and that the Heat is encreaſed by the Application of new Fire, and the Augmentation of the Agitation of the Fire which the Body itſelf contains; and therefore that *the Heat is not in proportion to the Quantity of Fire.* 588

As to the Motion of Light, it is plain, as we ſaid *, that it is perform'd in right Lines; but whether * 581

whether it be ſucceſſive or inſtantaneous, is diſputed; that is, whether at the ſame Moment that a Body begins to ſhine, the Light is ſenſible at any Diſtance, or whether the Light goes on ſucceſſively to Places more and more diſtant.

589 It ſeems clearly to follow from ſeveral Aſtronomical Obſervations, that that Motion is ſucceſſive, and Philoſophers did not long doubt of it; but by ſome later Obſervations, the Concluſions, drawn from the former, are weaken'd, and we are obliged to confeſs that the Motion of Light has ſomething unknown to us.

To ſay that a Motion from one Place to another is not ſucceſſive, implies a Contradiction,

590 and *it can ſcarce be doubted, that Light moves from one Place to another.*

For we obſerve that Fire is carried off in Vapours and Smoke; in which Caſe, Fire carries with it the Bodies to which it adheres, and yet is often mov'd very ſwift: If the Subtilty of Fire be conſider'd, it will eaſily be found that it is immenſly retarded by the Bodies to which it adheres; and, that, as ſoon as it is freed from them, it is mov'd with a very great Velocity.

There are ſeveral other Things very well worth obſerving, in reſpect to Light and Heat, but a great many of them are hard to explain. In natural Philoſophy, when we are ignorant of the Cauſes, we muſt only mention the Effects.

591 We ſee *ſeveral heated Bodies* that *become lucid, if their Heat be increaſed*; ſuch are Metals: They emit Fire by the Agitation of their Parts, but if the Motion of the Parts be increaſed, Part of the Fire is mov'd in right Lines, and the Body ſhines.

Thus

Thus if Smoke be made hotter by applying Flame to it, it is chang'd into Flame; that is, it becomes a lucid Body. 592

Experiment 1. *Plate* II. *Fig.* 3.] Having blown out the Candle C, which ſends out the Smoke F; let another lighted Candle A be brought to it, and the Smoke of the firſt will be chang'd into Flame, and that ſucceſſively quite to the Candle C, which is thus lighted by the Candle A, tho it be 7 or 8 Inches from it.

We have ſaid that Air acts upon Fire *; one of its Effects upon it, that in many Caſes is not to be overlook'd, ſhews itſelf in Reſpect of Light. For *the Preſence of the Air is often neceſſary for the Production of Light or Preſervation of Fire*, which may be obſerv'd in the burning of all thoſe Bodies that go out when the Air is taken away from them. * 577 593

Experiment 2.] Put a lighted Candle under the Receiver of the Air-Pump; exhauſt the Receiver, and the Candle will immediately go out.

Plate II. *Fig.* 2. *Experiment* 3.] Take a round Plate of Steel of about 3 Inches Diameter, with an Hole in the Middle to receive the Axis which is to be mov'd *in Vacuo* *, and let it be preſs'd and fix'd between two round Pieces of Wood by the Help of the Screws *d*, *d*; let Pieces of Flint be faſten'd to the Spring *f*, *f*, ſo that by the Motion of the Axis the Steel Plate may rub nimbly againſt the Flints. As long as there is any Air in the Receiver the Attrition will produce Sparks of Fire; when the Air is drawn out, tho you continue the Attrition, you can perceive no Light; but upon re-admitting the Air, it becomes again ſenſible. * 567

594 We obſerve alſo on the contrary, that *very often the Abſence of Air is neceſſary for Light*, as might be obſerv'd in the Experiments already
* 557 mention'd *. *And* laſtly, That *taking away the*
571 *Air, the ſame Light, which may be ſeen in the open*
595 *Air, is* ſometimes *increaſed.*

* 575 *Experiment* 4.] With the *Phoſphorus* * abovemention'd write or draw Figures upon Paper, and they will ſhine in the dark, as we ſaid before; but the Paper will become much brighter *in Vacuo.*

CHAP. IV.

Of the Dilatation occaſion'd by Heat.

596 ALL Bodies are dilated by the Action of
* 547 Fire *; but *that Dilatation* changes as the Heat changes; ſo that it *ſeems to depend rather upon the Motion than the Quantity of the Fire*; for Bodies are expanded as well by rubbing as by applying Fire to them externally.

Experiment 1. *Plate* III. *Fig.* 1.] Take a ſquare Iron Bar about 3 Foot long and $\frac{1}{4}$ of an Inch thick, and having laid it upon a Board between two firm Obſtacles or Standards O, O, between one of the Obſtacles and one End of the Bar, thruſt in an Iron Ruler about 4 or 5 Inches long, (made Wedge-Faſhion, being $\frac{1}{4}$ of an Inch broader at R than at *r*, and divided into equal Parts) as far as it will go; and obſerve the Diviſion that is againſt the End of the Bar, which muſt be a little oblique, that it may the better apply it ſelf to the Ruler.

Then let the Bar be heated, either by Attrition or Fire; then let it again be put between

the Standards, and the Ruler thruſt in between: As the Ruler will not go in ſo far as the Diviſion that was obſerv'd before, it is plain that the Bar is lengthen'd by Heat.

Experiment 2. *Plate* II. *Fig.* 4.] That *Liquids, as well as Solids, are dilated by Heat* may be prov'd in the following Manner. Take a Glaſs Ball G that has a ſmall Tube E D for its Neck, and fill it with ſome Liquor up to what Height you pleaſe in the Tube, and the Liquor will aſcend in the Tube, when you heat the Ball; a ſmall Degree of Heat will produce this Effect, even tho you uſe Mercury, the denſeſt of all Fluids. The Experiment will be made in the ſame Manner, but better, if inſtead of a Ball you uſe an hollow Cylinder C with the long Tube B A join'd to it; for the whole Liquor will be ſooner heated in a Cylinder than in a Ball. 597

If the Tube E D or B A be divided into equal Parts; or the Tube with its Ball or Cylinder be fitted to a Frame on which equal Diviſions are mark'd, the Heat may in ſome Sort be meaſured by this Machine: For the Liquor riſes or ſubſides in the Tube, as the Heat of the neighbouring Bodies is increas'd or diminiſh'd. Such Inſtruments are call'd *Thermometers*, and are of common Uſe. They do indeed ſhew a Change in the Heat, but it is uncertain whether they ſhew the Degree of Heat; that is, it is not known what Relation there is between the Change of Expanſion and the Change of Heat, ſo as to enable us to compare together the Degrees of Heat, by comparing the Degrees of Dilatation. 598 599

If the Ball G or Cylinder C be ſuddenly heated, the Liquor in the Tube will immediately deſcend, but immediately after riſe. By reaſon of the ſud- 600

den Heat the Glaſs it ſelf grows hot ſooner than the Liquor contain'd in it; and therefore when the Glaſs is dilated by the Heat, the Cavity grows bigger, ſo that the Liquor deſcends; but the Heat being preſently communicated to it, it riſes again by its Expanſion.

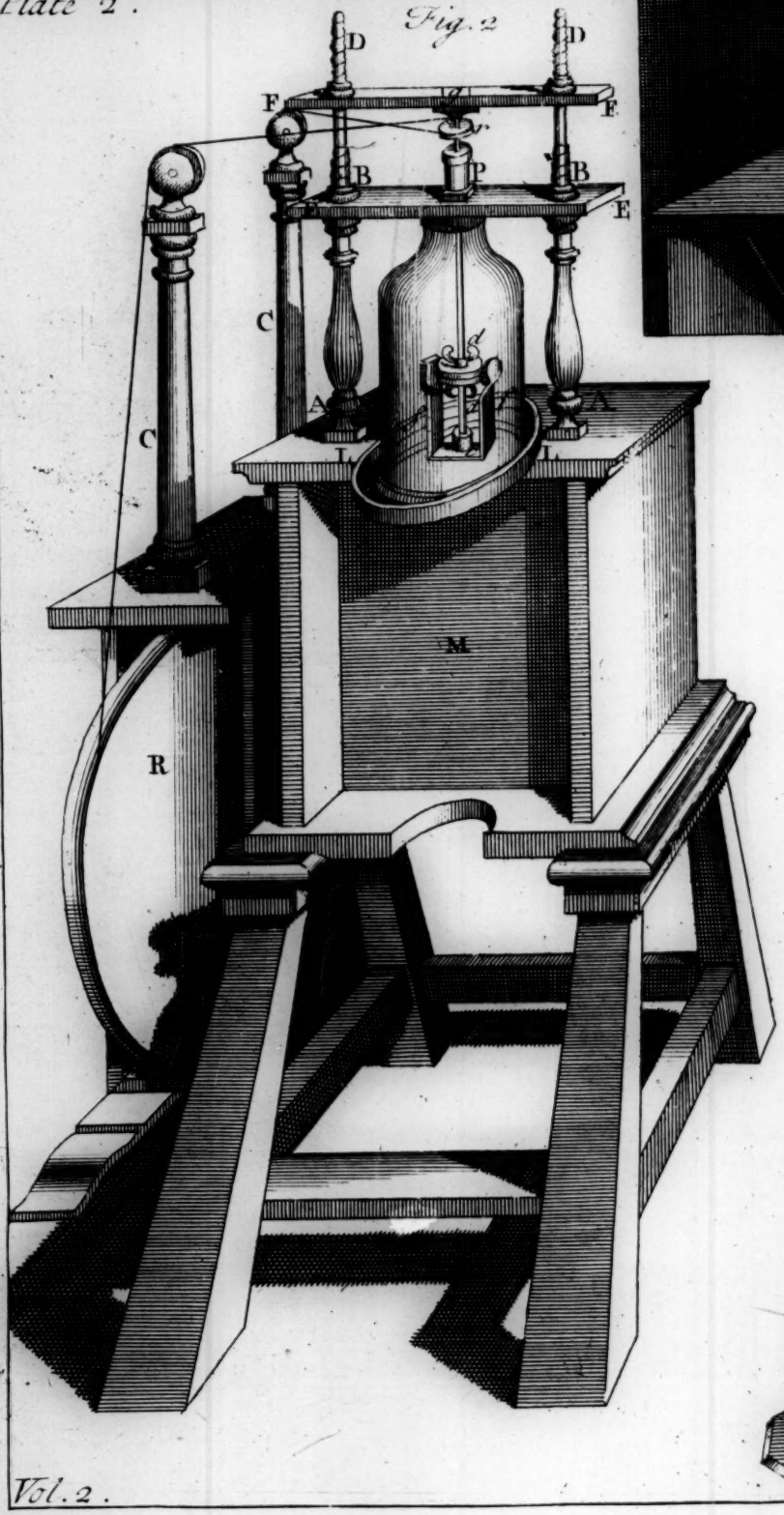
From the Expanſion of Bodies it is evident
601 that *the Particles of which Bodies conſiſt, from the Action of the Fire, acquire a repellent Force, by which they endeavour to fly from each other*, and which acts contrary to that Force by which the Parti-
*31 cles come to each other *. As long as this laſt Force is ſtronger than the other, the Particles cohere more or leſs, according to the different Degree of Heat. When the repellent Force is almoſt equal to the attractive, the Particles, which were before firmly join'd, ſcarcely cohere, yield to any Impreſſion, and are eaſily mov'd one among another; whence we ſee that *a So-*
602 *lid Body is chang'd into a Liquid by Heat*, which may be obſerv'd in all Bodies that are liquified by Heat, and return to their firſt State upon the Diminution of the Heat. It is a Queſtion,
603 *Whether all Fluidity is not owing to Heat?* which *cannot be determin'd*, becauſe we know of no Body that is entirely without Fire in it; it is certain that Heat is not only the Cauſe of Fluidity in Metals, Wax, and ſuch like Bodies, but that ſeveral Bodies, which are commonly reckon'd Fluid, are only ſo by reaſon of their Heat; thus
604 *Water is melted Ice*; for when Part of the Heat of the Water is gone, it grows fix'd.

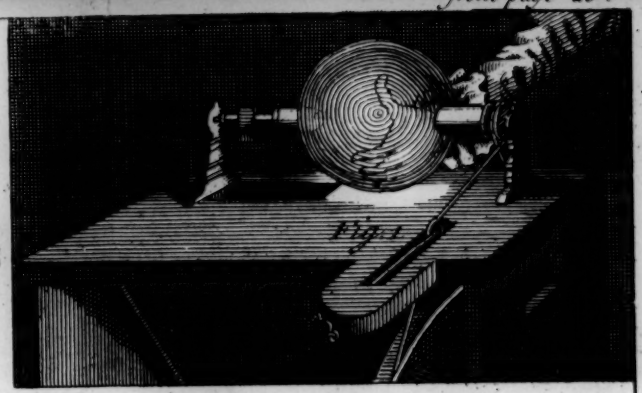
605 Heat may be ſo increas'd that in ſome Bodies the attracting Force is overcome by the repelling Force; in which Caſe the Particles fly from each other; that is, acquire an elaſtic
*431 Force, as the Particles of Air have *, which Elaſticity is increaſed even in the Air by Heat.

We

Plate 2.

Fig. 2





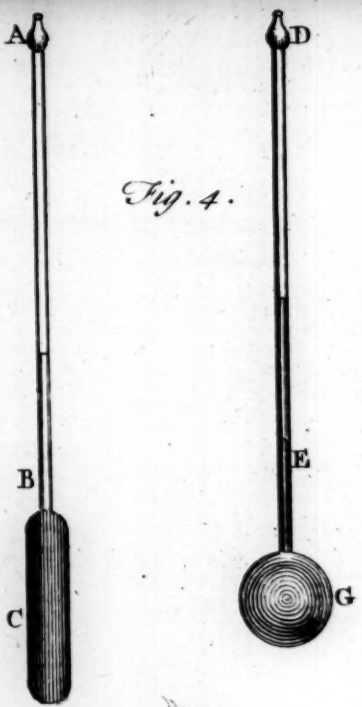
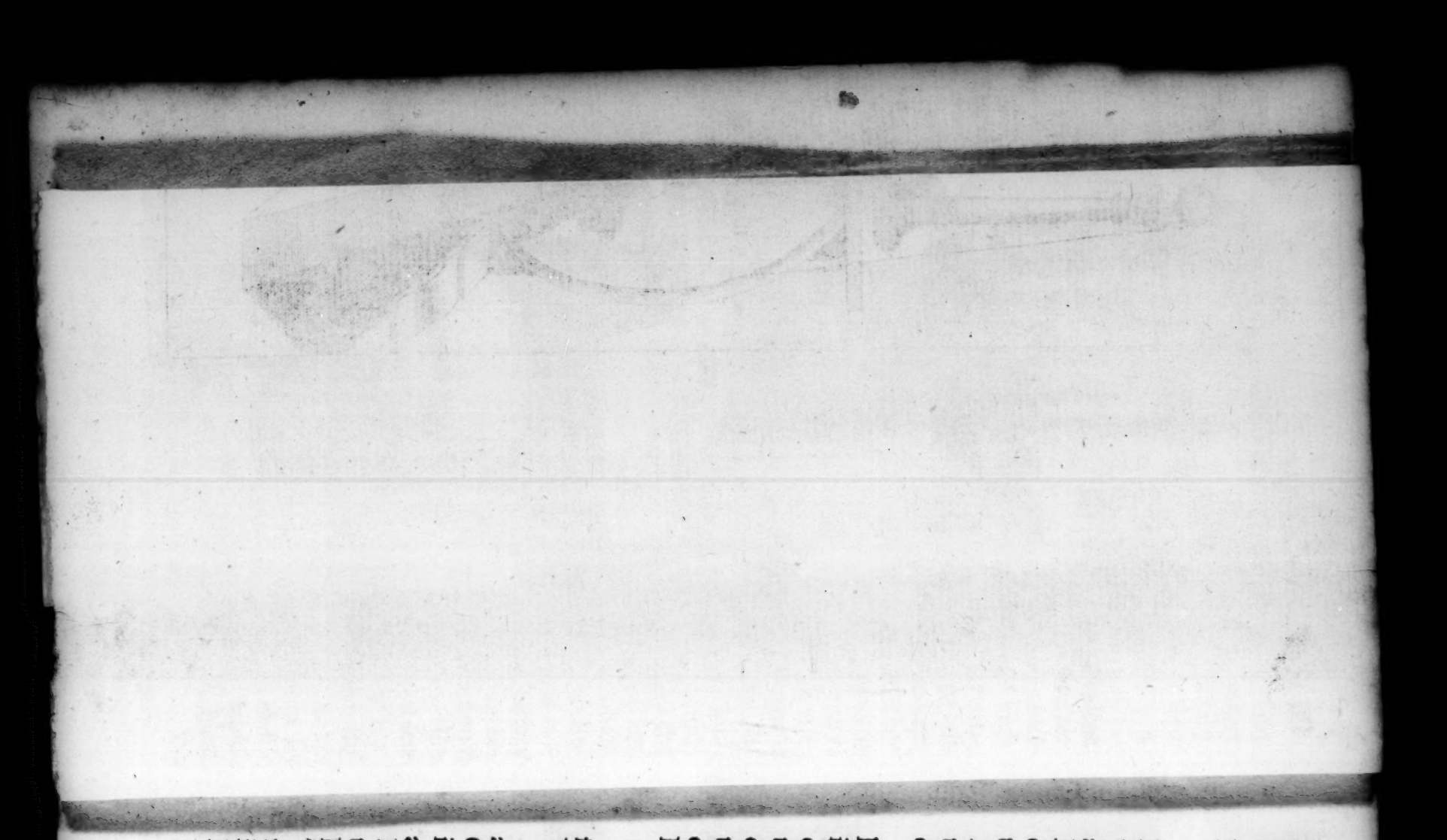


Fig. 4.



Fig. 3.

Vol. 2.



We may obſerve this Effect in Smoke and Vapours.

Experiment 3. *Plate* III. *Fig.* 2.] Take an hollow Braſs Ball E, of about 4 Inches Diameter, with an Handle M; This Ball has a Pipe T with an Hole of hardly the twentieth Part of an Inch. Let this Ball be heated, and the Air in it will expand itſelf * and come out thro' the Pipe; * 597
then, immerging the Ball in cold Water, the Air will be again condens'd by the Cold, and the Water will go into the Ball, by the Preſſure of the Atmoſphere upon its Surface.

If this Ball, thus partly fill'd with Water, be laid upon the Fire, the Moment that the Water is chang'd into Vapours, thoſe Vapours will go out thro' T; but if the Heat be increas'd, ſo as to make the Water boil violently, the Vapours, compreſs'd in the upper Part of the Ball, will, by their Elaſticity, endeavour to recede from each other every Way, and ruſh violently out of the Pipe. Such an Inſtrument is call'd an *Æolipile*. 606

Experiment 4.] The following Experiment 607
ſhews a more ſenſible Effect of the Elaſticity of Vapours.

Plate III. *Fig.* 3.] Take the Ball E, which is alſo of 4 Inches Diameter, made of Braſs or Copper, but thicker than the former, and let it be placed upon a little light Cart, ſuch as is repreſented in the Figure. In its upper Part, it has a ſquare Pipe T. In the middle of this Pipe, there is a Separation, and the hind Part of the Pipe communicates with the Ball. There is an Hole of about ¼ of an Inch, in the middle of the Separation of the Pipe, which Pipe is open forwards. This Hole is ſhut up with a long Plate, that goes thro' two Holes in the

Sides of the Pipe, and applies itſelf to the above-mention'd Separation. As the Plate is made Wedge-wiſe, if you ſtrike upon it with a Hammer, it will exactly ſhut the Hole.

Take this Ball off of the Cart, and open the Hole, and, having heated the Ball, immerge it in Water, to let it be in Part fill'd, as in the laſt Experiment. Then, having ſhut the Hole, ſet the Ball again upon the Fire, till the Water boils violently; and then if you make it faſt to the Cart, and open the Hole, the Vapour will fly out violently one Way, and the Cart be carried with the Ball the contrary Way.

608 The Vapour, being very ſtrongly compreſs'd, endeavours to recede equally every Way, and therefore oppoſite Preſſures deſtroy one another; but when the Hole is open'd, the Vapour, which goes out, does not preſs; therefore the Preſſure one Way being taken off, that which acts in a contrary Direction prevails, and the Cart is mov'd along.

609 A Sky-Rocket riſes up into the Air, becauſe the Gun-powder, being ſet on Fire, acquires an Elaſticity, and its Parts endeavour to recede every Way: As the Pipe, or Caſe of it, is open at one End, it is leſs preſs'd that Way, and conſequently at the other End, the Preſſure prevails, and carries up the Rocket.

BOOK III.

PART II.

Concerning the Inflexion, Refraction, and Reflexion of Light.

CHAP. V.

Concerning the Inflexion of the Rays of Light.

HAVING premis'd, in the foregoing Part, what regards Fire in general; let us again farther examine the Properties of Light and the Phænomena arising from them.

The Things obſerv'd concerning Light are very wonderful, yet moſt of them are explain'd by a few Laws of Nature.

Light moves in right Lines *, can be intercepted by an Obſtacle which wholly ſtops ſo much Light as comes upon it, but ſtops no more. * 581

DEFINITION.

Any Light conſider'd according to the Direction of its Motion, if it be all carried in the ſame Direction, is call'd, a Ray of Light. 610

Such is a Beam of the Sun's Light going thro' an Hole.

Fire, as has been ſaid, is attracted by Bo-
* 549 dies * ; the notable Effects of which Attraction may be obſerv'd in the burning of Bodies ; they
611 are alſo ſenſible in Light ; for *when Light paſſes near Bodies, it is turn'd out of the ſtrait Way* ; which may be diſtinctly perceiv'd by the following Experiment.

Experiment 1. *Plate* III. *Fig.* 4.] Take a little Board T about 6 Inches long, and as high, with an Hollow *c c* in its Surface, in which two Plates of Steel ſlide, each of which has an Edge like a Knife ; the two Edges may be brought together in the middle of the Board, and be join'd together exactly. At the Place where they meet, there is a ſquare Hole in the Board, of almoſt an Inch, that a Beam of Light, let into a dark Room thro' an Hole of a Quarter of an Inch in Diameter, may paſs thro' the ſaid ſquare Hole, ſo as to come to the Plates.

If the Diſtance between the ſaid Edges be of about the 10th Part of an Inch, and the Light be made to paſs between them, the Board being ſet at the Diſtance of 3 Foot from the Window, if the Light falls upon the Paper A, at 5 Foot beyond the Board, there will appear, on each Side of the tranſmitted Beam, a Light like that of the Tail of a Comet ; which proves that the *Light is inflected* as it paſſes by the Edges of the Plates, as is plain from the Figure.

If you bring the Plates nearer (as for Example) within the hundredth Part of an Inch, inſtead of the Light above-mentioned, you will, on each Side of the Light of the Beam upon the Paper, ſee three colour'd Fringes, parallel to the Edges

Edges of the Plates; which will ſtill appear more diſtinct, if the Hole in the Window be made leſs. I ſhall hereafter explain whence theſe Colours ariſe. Now it is enough to deduce from this Experiment, that Light *is attracted* by Bodies that inflect its Rays; for if there was not a Motion towards the Body, the whole Beam would have continu'd in its direct Motion.

But *the Action of Bodies, by which they act upon the Light to attract it, exerts itſelf at a ſenſible Diſtance*; as is plain from the Experiment. 612

Experiment 2. *Plate* III. *Fig.* 4.] Every thing elſe being as in the former Experiment, if the Plates be brought nearer together within $\frac{1}{400}$ Part of an Inch, no Light will appear upon the Paper between the Fringes above-mention'd; ſo that in this Caſe, all the Light, which paſſes between the Edges, is inflected on either Side, ſo as to produce the Fringes above-mention'd. Which plainly ſhews, that Steel acts upon Light at leaſt at the Diſtance of $\frac{1}{800}$ Part of an Inch.

It is alſo proved, that *That Action is increas'd as the Diſtance is diminiſh'd.* 613

Experiment 3. *Plate* III. *Fig.* 4.] Things being ſtill in the ſame Diſpoſition, leſſen the Diſtance between the Plates; and the Fringes will vaniſh ſucceſſively, till the Plates being join'd together, no Light paſſes between them. The Fringes, which vaniſh firſt, are thoſe that are produced by the Rays which are leaſt inflected; and thoſe vaniſh laſt, which are produced by the Rays that are moſt inflected; that is, when the Edges come towards one another, the Shadow between the Fringes, made by each Edge, is continually increas'd, till, at laſt, the whole Light on each Side vaniſhes. Whence it plainly follows, that the

the Rays are more inflected, the nearer they pass by the Edges; that is, the Attraction is increased, as the Distance is diminish'd.

614 But this Attraction has something particular, for *the Attraction of one Edge is increased, as the other is brought near it.* Which is plainly seen in this Experiment; for as the Edges are brought towards one another, the Inflection of the Rays continually becomes greater.

CHAP. VI.

Concerning the Refraction of Light and its Laws.

615 *ALL that gives Passage to Light, is call'd a* Medium.

Glass, Water, and a Vacuum itself are Mediums.

When a Ray of Light goes out of one Medium into another, it is often turn'd out of the right Line.

DEFINITION II.

This Inflection is call'd *Refraction.*

616 *In order to produce Refraction, the Mediums must be of different Densities, and the Ray must make an oblique Angle with the Surface that separates the Mediums.*

618 *Refraction arises from this, that the Rays are more attracted by a dense, than by a rare Medium*; from which Attraction, that we have prov'd in the foregoing Chapter, all that relates to Refraction may be deduced.

619 Let E F be the Separation of the Mediums [*Plate* IV. *Fig.* 1.] and let X be in the denser, and Z in the rarer Medium. All the Particles have
* 31 an attractive Force *, and this Force also obtains
* 611 in Light. Let the Distance, at * which the Particles exert their Action, be that which is comprehended between the Lines E F and G H.

Therefore,

Plate 3.

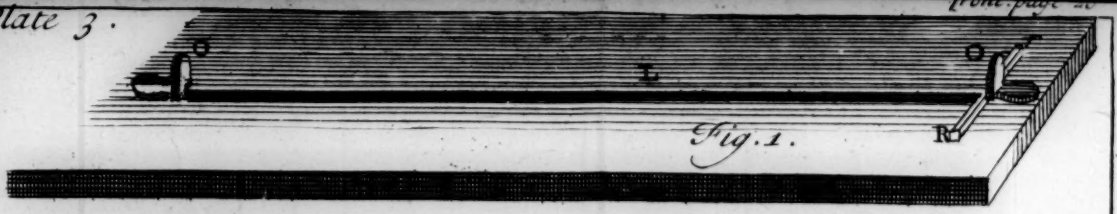


Fig. 1.

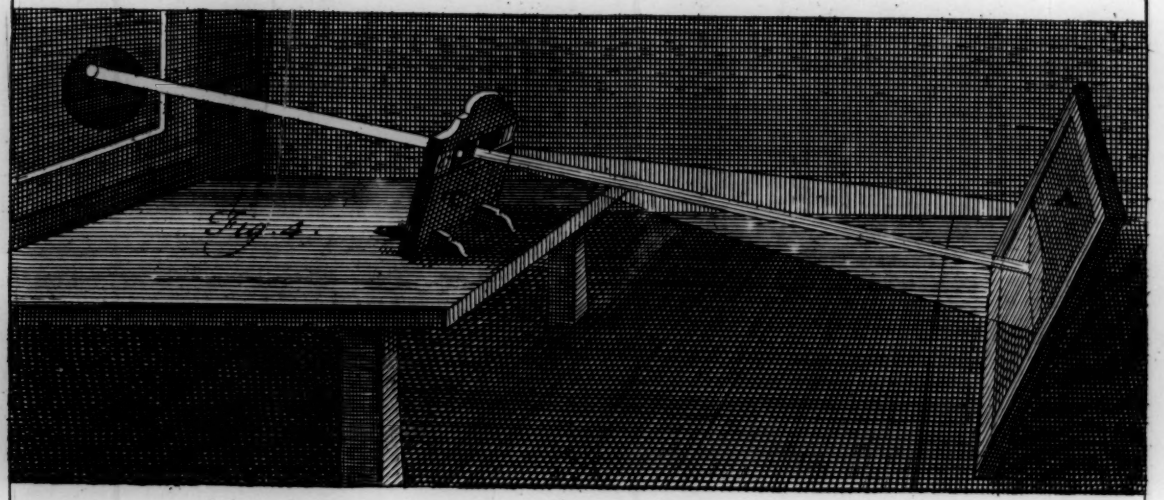


Fig. 4.

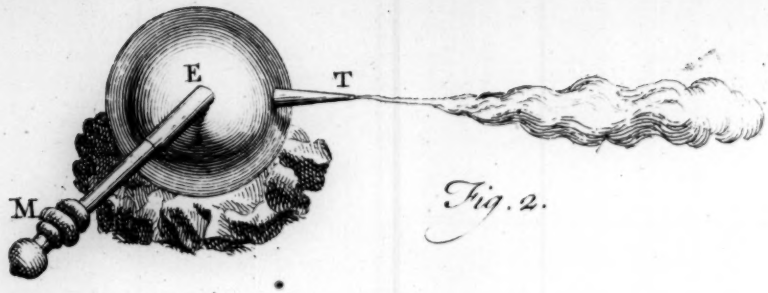


Fig. 2.

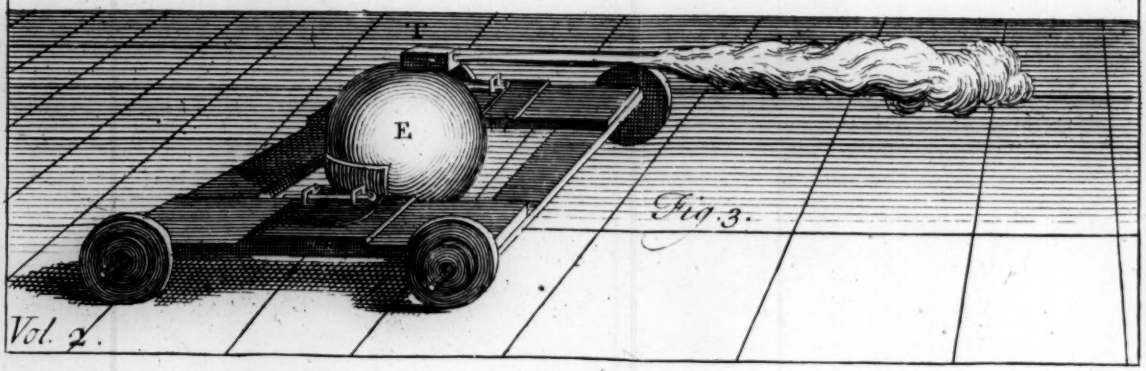


Fig. 3.

Vol. 2.

Therefore, the Light, which comes between thoſe Lines, will be attracted by the Medium X.

At the Diſtance of the Line G H, only the extreme Parts of the Medium X act upon the Light; at a leſs Diſtance, both they and other Parts act ſo as to increaſe the attracting Force, when the Diſtance is diminiſh'd, as has been before obſerved *. In the denſer Medium X, let the Line I L be ſuppoſed at the ſame Diſtance from E F as G H is in the Medium Z. Let the Light enter into the Medium X, and it will, on all Sides, be attracted by the Particles of the Medium, whoſe Diſtances from the Light are leſs than the Diſtance between E F and G H; for the Light is ſuppos'd to be attracted at that Diſtance by the Particles of the Medium X. * 613

As long as the Light is between the Lines E F and I L, the attracting Force is the ſtrongeſt towards I L, becauſe there are more Particles that draw that Way; but as the Number of Particles, that act the contrary Way, increaſes, that is, as the Diſtance from E F increaſes, the Force towards I L is diminiſh'd, till, in the very Line I L, the Light be equally attracted every Way; which alſo obtains every where in the Medium X, beyond I L.

Suppoſe a Ray of Light to come in the Line A *a*, and fall obliquely on the Surface, which divides the Mediums, or rather on the Surface G H, where the Action begins, by which the Light is driven towards the Medium X: When the Ray comes to *a*, it is turn'd out of the right Line, by the Force by which it is attracted by the Medium X; that is, by which it is driven towards it in a Direction perpendicular to its Surface. And, indeed, the Ray of Light is bent out of the right Line in every Point, as long as it is between the Lines G H and I L, between which

which the ſaid Attraction acts; and therefore between thoſe Lines, it deſcribes the Curve *a b*,
* 208 in the ſame Manner that Projectiles move *. Beyond the Line I L, the Action which bends the Ray ceaſes; therefore it goes on then in a right Line, according to the Direction of the Curve in the Point *b*.

The Diſtance, between the Line G H and I L, is very ſmall; therefore, when we conſider Refraction, we take no notice of the bended Part of the Ray, which we look upon as if it was made up of two ſtrait Lines A C, C B, meeting at C, namely, on the Surface which divides the Mediums.

Thro' C draw N C M, perpendicular to the Surface of E F.

Definition III.

620 *The Part* A C *of the ſaid Ray is call'd the incident Ray.*

Definition IV.

621 *The Angle* A C N *is call'd the* Angle of Incidence.

Definition V.

622 *The Part* C B *is call'd the* Refracted Ray.

Definition VI.

623 *The Angle* B C M *is call'd the* Angle of Refraction.

624 In this Caſe, *When Light goes out of a rare into a denſe Medium, the Angle of Refraction is leſs than the Angle of Incidence*, by reaſon of the Inflexion of the Ray; for theſe Angles wou'd be equal, if the Ray A C continu'd to move ſtrait on in the Line C D. The Ray C B does alſo come nearer to the Per-

Perpendicular C M; and therefore *the Refraction is ſaid* to be *made towards the Perpendicular.*

On the contrary, *if the Ray goes out of a denſer into a rarer Medium, it will recede from the Perpendicular*, becauſe the denſer Medium attracts the Ray in the ſame Manner, whether it goes out of a rarer into a denſer, or out of a denſer into a rarer Medium. Therefore if B C be the Ray of Incidence, C A will be the refracted Ray; that is, *Let the Ray come from either Side, and it will move in the ſame Lines.* Therefore, *if there be two Rays, and one comes out of a denſer Medium into a rarer, and the other out of a rarer into a denſer, and the Angle of Refraction of the one be equal to the Angle of Incidence of the other, the two remaining Angles of Incidence and Refraction will be equal to each other.* 625 626 627

Whence it follows, that *The Direction of the Ray is not chang'd, if it moves thro' a Medium termined by two Surfaces parallel to each other*; for as much as it is turn'd towards any Side at its Entrance, ſo much exactly is it turn'd the other Way as it goes out of the ſaid Medium. 628

If a Ray falls perpendicularly on the Surface that ſeparates two Mediums, it will not be turn'd out of the right Line by the Attraction of the denſer Medium; becauſe in that Caſe it acts in the Direction of the Ray. 629

Plate IV. *Fig.* 2.] To confirm what we have ſaid by Experiments, take a Trough or open Box P, about a Foot long, 4 Inches wide, and of the ſame Depth. Its two Sides *a b c d*, *a b c d*, are Planes of Glaſs parallel to each other, and this Box muſt be fill'd with Water two Inches and half high. 630

The Experiments muſt be made in a dark Place; the Light muſt be let in thro' a Slit in the moveable round Plate O, which is fix'd to the Wind-

Window-ſhut, and is eaſily turn'd round, that the Slit may be inclin'd at Pleaſure: The Slit is 4 Inches long and $\frac{1}{8}$ Inch wide.

The Light, that is let in, ſtrikes upon the Looking-Glaſs S, and the Slit is ſo inclin'd, and Speculum diſpoſed, that the Beam, that comes thro' the Slit, may be horizontally reflected by the Looking-Glaſs, the Beam being in a vertical Poſition, that it may go thro' a vertical Slit in the Board T, of the ſame Dimenſions as that in the Plate O. This Board is us'd to diminiſh the Breadth of the Beam, which is continually increaſing, by reaſon of the Light that comes from the Sides of the Sun.

Experiment 1.] Things being diſpos'd, as we have ſaid in the Deſcription of the Machine; let the Beam fall perpendicularly on the Surface *a b c d*, and it will paſs perpendicularly thro' the Water and the upper Part of the Trough, and not be turn'd out of the Way at all, either going in or coming out; by which is confirm'd what has been ſaid (N°. 629.)

Experiment 2.] Now let the Beam fall obliquely on the Surface *a b c d*, at *f g*; the upper Part of the Beam will continue its Motion ſtrait along *h*; but the lower Part of it, in the Water, will be bent towards *i*, coming towards the Perpendicular; which confirms (N°. 624.)

Experiment 3.] Every Thing being, as in the former Experiments, the Beam, which, at *i*, goes out of Water into Air, is turn'd out of its Way fromwards the Perpendicular, and in ſuch Manner, as to move in the ſame Direction as the incident Ray that goes into the Water at *g*; for it goes

goes on parallel to the Ray *f h* continued: which confirms (N°. 625, 626, and 628.

In what has been ſaid hitherto, we have only conſider'd the Attraction of the denſer Medium, becauſe it overpowers; but we muſt not overlook the Action of the rarer Medium, becauſe it diminiſhes the Action of the denſer, which Action becomes ſo much the leſs on the Rays of Light, as the Mediums differ leſs in Denſity. Therefore *there is no Refraction where the Denſities of Mediums are equal; and the Refraction is greateſt where the Denſities of Mediums differ moſt.* 631

The Laws of Refraction are deduc'd from the Acceleration which the Attraction generates; therefore this Acceleration muſt be examin'd.

Definition VII.

The Space, terminated by the Planes G H and I L, is call'd the Space of Attraction. 632

Plate 4. *Fig.* 1.] The Attraction acts between the Planes repreſented by theſe Lines, but no farther *. * 619.

The Direction of this Action is perpendicular to the Surface that ſeparates the Mediums, and conſequently to the Surface I L; *and its Form is unequal at different Diſtances from the Surface* *. *But it is equal at equal Diſtances*, becauſe both Mediums are ſuppoſed homogeneous, and alike in all their Parts. 633 * 619.

The Motion of the Ray A C may be reſolved into two other Motions, according to the Directions A O and O C *, of which the firſt is parallel to the Surface E F, and the ſecond perpendicular to that Surface: The Celerities of which Motions will be reſpectively proportional to thoſe Lines A O and O C, whilſt A C denotes the Celerity of the Ray itſelf *. * 192. * 192.

The

634 *The Motion, according to the Direction* A O, *is not chang'd by the Attraction perpendicular to the Surface* I L, *only the Motion according to* O C *is accelerated.*

635 Keeping the Line A C, that is the Celerity of the Ray, its Inclination may be chang'd, whereby alſo the Celerity in the Direction O C is alſo chang'd; which Celerity wholly vaniſhes, if the Angle A *a* G be very ſmall. In which Caſe, if after Light has enter'd into a denſer Medium, its Motion be reſolv'd into two, ſo that the Direction of the one be perpendicular to the Surface I L, its Celerity muſt be wholly attributed to the Attraction ſo often mention'd. For, as it enters into the Space of Attraction, a Motion is generated in that Direction; and, as it goes thro' that Space, in which a new Action does every where act upon the Light in the ſame Direction, it is continually accelerated. Which Acceleration obtains in every Paſſage of Light thro' the Space of Attraction; but it is different, according to the different Celerity with which Light comes perpendicular to the Surface which parts the Mediums.

If the Attraction was equable thro' the whole Space of Attraction, the Laws concerning the ſaid Attraction might be determin'd (as was ſaid of the Acceleration of heavy Bodies after N° 130.) by Help of the rectangular Triangle P Q R, (*Plate* IV. *Fig.* 3.) in which the Lines parallel to the Baſe repreſent the Celerities, whilſt Portions of the Area of the Triangle repreſent the Spaces gone thro'.

But here we have always the ſame Space run thro', namely the Breadth of the Space of Attraction, becauſe we only conſider the Motion which is perpendicular to the Surface, which ſeparates the Mediums; therefore that Space is always repreſented by equal Parts of the Area of the Triangle P Q R. Let P *d c* repreſent ſuch a

Part when the Celerity is equal to *o*. The Light enters the Space of Attraction in the above-mention'd perpendicular Direction, that is, when an incident Ray makes a very ſmall Angle with the Surface that ſeparates the Mediums; *d c* in that Caſe will denote the Celerity acquir'd by the Attraction, and with which the Light goes out of the Space of Attraction.

But if the Light goes perpendicularly into the Space of Attraction with the Celerity that is expreſs'd by *f g*, it will go out of that Space with the Celerity *h i*, ſuppoſing the Areas P *d c* and *f g i h* equal to one another, as appears from what has been ſaid. The Triangle P *dc*, P*fg*, P *hi* are Similar, and therefore their Areas are to one another, as the Squares of the homologous Sides *d c*, *f g*, *h i*; but the Sum of the Areas P*dc*, P*fg*, is equal to the Area P*hi*; (by reaſon of the equal Areas P *d c* and *f g i h*;) therefore alſo the Sum of the Squares of the Lines *d c* and *f g* is equal to the Square of the Line *hi*; whence it follows, that with the three Lines above-mentioned one may form a rectangular Triangle, whoſe Hypothenuſe will be *h i*.

Therefore, *In a rectangular Triangle, one Side of* 636
which is the Celerity with which Light enters the Space of Attraction perpendicularly, and the other Side the Celerity acquir'd in going thro' that Space, when the Celerity with which the Light enters into it is equal to o; *the Hypothenuſe of the Triangle will be the Celerity with which the Light goes perpendicularly out of the Space of Attraction on the other Side:* Which univerſally obtains, which way ſoever the Attraction is chang'd, in the Space of Attraction, according to the different Diſtance of the Planes that terminate that Space. Which to prove,

Let us ſuppoſe the Space of Attraction to be divided into two Parts, whether equal or un-

equal, by a Plane parallel to the Surfaces with which it is terminated. Let us ſuppoſe beſides, that the Attraction is not the ſame in thoſe two Parts, but yet that it does not vary in one of them. Theſe Parts are to be conſider'd as two different Spaces of Attraction. Let A (*Plate* IV. *Fig.* 4.) be the Celerity which the Light acquires in going thro' the firſt Part of the Space, when it enters the Space with the Celerity O. Let B be the Celerity acquir'd in going thro' the ſecond Part of the Space, when the ſame Light enters that Part with the Celerity O. It is to be obſerv'd that this Demonſtration relates to the Motion, perpendicular to the Surface, which ſeparates the Mediums.

Let the Light enter the firſt Part of the Space above-mention'd with the Celerity O, it will come to the ſecond with the Celerity A; if therefore a right angled Triangle be form'd with the Sides A and B, the Hypothenuſe E D will expreſs the Celerity with which the Light will go out of * 636 the Space of Attraction *.

If the Light enters the Space of Attraction with the Celerity F G, let the rectangular Triangle H F G be drawn with the Sides F G and A; the Hypothenuſe H G will be the Celerity, with which the Light goes out of the firſt Part of * 636 the Space of Attraction *, and enters into the ſecond; and if you draw the rectangular Triangle H G I, whoſe Perpendicular is equal to the Line B, you will have the Hypothenuſe I G to denote the Celerity with which the Light goes out, and continues its Motion after it has run * 636 thro' the whole Space of Attraction *.

Now we muſt demonſtrate that the Celerity I G is alſo the Hypothenuſe of the rectangular Triangle N M L, whoſe Side M L is equal to the Celerity F G, with which the Light enters the Space

Space of Attraction; and whoſe other Side L N is equal to the Line E D, which is the Celerity that the Light acquires in going thro' the whole Breadth of the Space of Attraction, when it has enter'd it with the Celerity O; which being alſo demonſtrated in that Caſe, in which two different Forces of Attraction act, it is plain that the Propoſition of N° 636 is thereby prov'd.

But it is plain from the Conſideration of the rectangular Triangles, that the Lines I G, and N M, are equal. The Square of the Line N M is equal to the Squares of the Lines N L and L M or F G: N L is equal to the Line E D, whoſe Square is equal to the Squares of the Lines E C and C D, or of the Lines A and B, which are equal to F H and H I: therefore the Square of the Hypothenuſe N M is equal to the three Squares of the Lines F G, F H, and H I. To which three Squares, the Square of the Lines G I is equal; as having been prov'd equal to the Squares of the Lines H I and H G, which laſt is equal to the Squares of the Lines H F and F G.

If the Space of Attraction be divided into ever ſo many Spaces by plain parallel Surfaces, which terminate that Space, and the different Parts have different Forces of Attraction, the ſame Demonſtration will ſerve; and the Number of Diviſions may be made any how *in infinitum*; which Caſe obtains in the Refraction which Light ſuffers going out of any Medium into another of different Denſity*: *to* which *Refraction* therefore *the Rule of* N°. 636 *may be applied.* 637 * 636

Plate IV. *Fig.* 5.] Let Z be the rarer, and X the denſer Medium, and let them be ſeparated by the Plane E F; let a Ray of Light A C fall obliquely on the Surface E F; let A C denote the Celerity of the Light in the Medium Z, and

let that Line A C be ſettled; that is, let it be always the ſame, whatever the Inclination of the Ray is. With the Center C and the Semidameter C A, draw a Circle; and let N C M be drawn perpendicular to E F; from A, draw A O perpendicular to N C, and A Q to E F.

Let us conceive the Motion along A C reſolv'd into two others, the one along A O, and
* 192 the other along A Q or O C *; the Line O C will denote the Ray's Celerity perpendicular to the Surface E F, which Celerity alone is in-
* 634 creaſed by the Attraction of the Medium *.

Let C P be the Celerity which Light acquires, in paſſing perpendicularly thro' the Space of Attraction of the Medium X; ſuppoſing the Celerity of Light at its Entrance to be O, the Hypothenuſe O P of the rectangular Triangle P C O will be the Celerity of the Ray A C in the Medium X, according to a Direction perpendi-
* 637 cular to the Surface E F *; the Celerity of the Light in the Direction A O or Q C, parallel to
* 634 the Surface E F, is not chang'd *. Therefore let C V be equal to A O or Q C, and V B perpendicular to E F, equal to the Hypothenuſe P O, and draw C B; the Motion along C B is compounded of the Two, and this Line by its Situation determines the Direction, and by its Length
* 190 *the Velocity of the Light in the Medium* X *; which
638 Celerity *is not chang'd by the different Inclination of the Ray* A C. For the Square of the Line C B is equal to the Square of the Line B V or P O, the Square of the Line C V or A O; but the Square of the Line P O is equal to the Squares of the Line P C and C O: Therefore the Square of the Line C B is equal to the three Squares of the Lines P C, C O and A O; which two laſt, if join'd, will give us the Square of the Semidiameter A C or C N; that is, C B is equal

to

to P N, whoſe Square is alſo equal to the Squares of the Lines P C and C N, and which undergoes no Change from the different Inclination of the Ray A C.

The Line C B does in T cut the Circle, which is deſcrib'd with the Semidiameter C A; from the Points B and T, draw B S and T R perpendicular to C M; by reaſon of the Similar Triangles C B S, C T R, B C will be to T C or C A, as B S to T R; which Lines therefore, by reaſon that B C and C A are ſettled, will have the ſame Ratio to one another, whatever be the Angle of Incidence. T R is the Sine of the Angle of Refraction T C R, and B S which is equal to C V, that is equal to A O, is the Sine of the Angle of Incidence A C O.

Therefore, *in every Inclination of the Incident Ray, there is a ſettled and conſtant Ratio between the Sines of the Angles of Incidence and Refraction.* 639

Now ſince B C and C A which are as the Sines above-mention'd, do alſo denote the Celerities of the Light in *the* Mediums X and Z, it follows that thoſe *Sines are inverſly, as the Celerities in the Mediums.*

If the Medium Z be Air, and X Water, the aforeſaid Sines are as 4 to 3; and the Celerity of the Light in Air to its Celerity in Water, as 3 to 4. But if, Z being ſtill taken for Air, X be Glaſs, the Sines will be as 17 to 11. One Experiment determines this for all Mediums. 640

The Ratio between the Sines of any Angles is the inverſe Ratio of the Secants of the Complements, as it appears in this Figure, ſuppoſing a Circle drawn with the Semidiameter C Q or C V; for then A C (which is equal to C T) and C B will be the Secants of the Angle A C Q, and B C V Complements to the Angles of Incidence and Refraction, and inverſly, as B S (which is 641

equal to A O) and T R, which are the Sines of Incidence and Refraction in the greater Circle.

And this Proportion of the Secants gives us a Method of eaſily reducing to Experiment the *Prop.* of N°. 639.

Experiment IV. *Plate* IV. *Fig.* 6.] In this Experiment the Light is to be let into the dark Chamber thro' a Slit, in the ſame Manner as in the former Experiments, and by means of a Looking-Glaſs reflected thro' the vertical Slit in the Board T.

Take a Trough P, nearly of the ſame Size as that which was us'd in the former Experiments, but which has only one End of Glaſs, namely, the little Side *a b c d*. And let it be half fill'd with Water.

The vertical Beam of Light being made to fall obliquely on the Glaſs End of the Trough, the Part of it, which is above the Water, goes directly forwards, and at *h* falls upon one of the long Sides of the Trough; but that Part of the Beam, which is refracted in the Water, goes along *g i*, and ſtrikes againſt the ſame Side of the Trough at *i*. Whatever the Angle be which the Beam makes with the End or Side *a b c d*, the Lines *f h* and *g i* will always be to each other, as 3 to 4; as is very eaſily ſhewn in ſeveral Inclinations, if you have two Scales, each with ſmall Diviſions on them; which Diviſions in the one muſt be to the Diviſions in the other, as 3 to 4: For the greater Line *g i* will always contain as many of the great Diviſions, as the leſſer Line *f h* will contain of the ſmall ones. The Angle, which *f h* makes with the Plane *a b c d*, is the Complement of the Angle of Incidence to a right

a right Angle, and the Angle made by the Line *g i* with the ſame Plane is the Complement of the Angle of Refraction to a right Angle; therefore *g h* and *g i* are the Secants of the Complements of the Angles of Incidence and Refraction, which have a conſtant Ratio to one another, as was to be confirm'd by this Experiment.

We have hitherto conſider'd a Ray of Light 642
going out of a rarer into a denſer Medium, but the ſame conſtant Proportion of the Sines mention'd, N°. 639, holds good alſo in the contrary Motion of the Rays; the Angles A C N, M C B (*Plate* IV. *Fig.* 5.) are not chang'd, whether the Incident Ray be A C or B C*. In that Caſe, if * 626
B C be the Celerity of the incident Ray, C A will be the Celerity of the refracted Ray; for the Motion of the Ray, going out of X into Z, is retarded in the ſame Manner by the Attraction towards the Medium X, as it is accelerated in the contrary Motion.

CHAP. VII.

Of the Refraction of Light, when Mediums are ſeparated by a plane Surface.

DEFINITION I.

RAys *proceeding from the ſame Point, as a Center, and continually receding from each other, are ſaid to be* divergent. 643

DEFINITION II.

Thoſe diverge more, *which make a greater Angle with each other.* 644

Definition III.

645 *The Point, from which the divergent Rays proceed, is call'd the* Radiant Point.

646 *The more the Rays diverge, ſuppoſing them at equal Diſtances from each other, the leſs is the ra-*
647 *diant Point diſtant from them; and ſo on the contrary,* the Rays are often mov'd by *Refraction,* as if they came from a radiant Point, tho they do not really proceed from ſuch a Point; that is, if the Rays ſhould be continued or produced back the Way from whence they come, they would meet in one Point. In that Caſe alſo, the Rays are ſaid to be divergent.

Definition IV, and V.

648 Rays *which concur in one Point, or would concur if they were continued, are ſaid to be* convergent;
649 *and thoſe are* more convergent, *which make greater Angles between themſelves.*

Definition VI.

650 *The Point of the Concourſe of converging Rays, is call'd the* Focus.

Definition VII.

651 *The Point, in which converging Rays, and ſuch as (being intercepted or turned out of the Way before their Concourſe) would have concurred, being continued, is called the* imaginary Focus. Which Name is alſo given to that Point from which thoſe divergent Rays are conceived to flow,
647 which do not proceed from the radiant Point.

652 *The more the Rays converge, ſuppoſing their Diſtance from each other to be the ſame, the leſs Diſtance from them is the Focus, whether real or imaginary.*

Plate 4.

front page 40

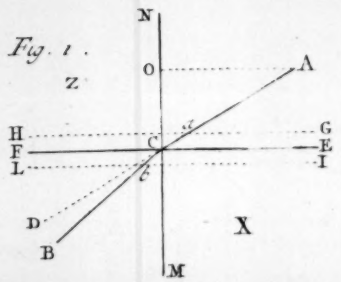


Fig. 1.

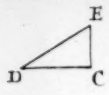
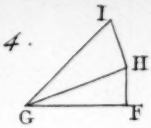
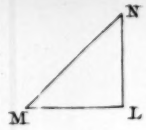


Fig. 4.





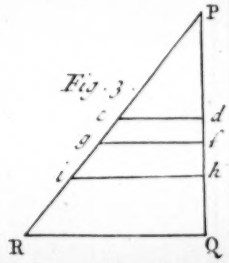


Fig. 3.

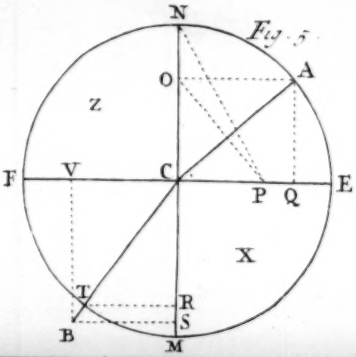


Fig. 5.

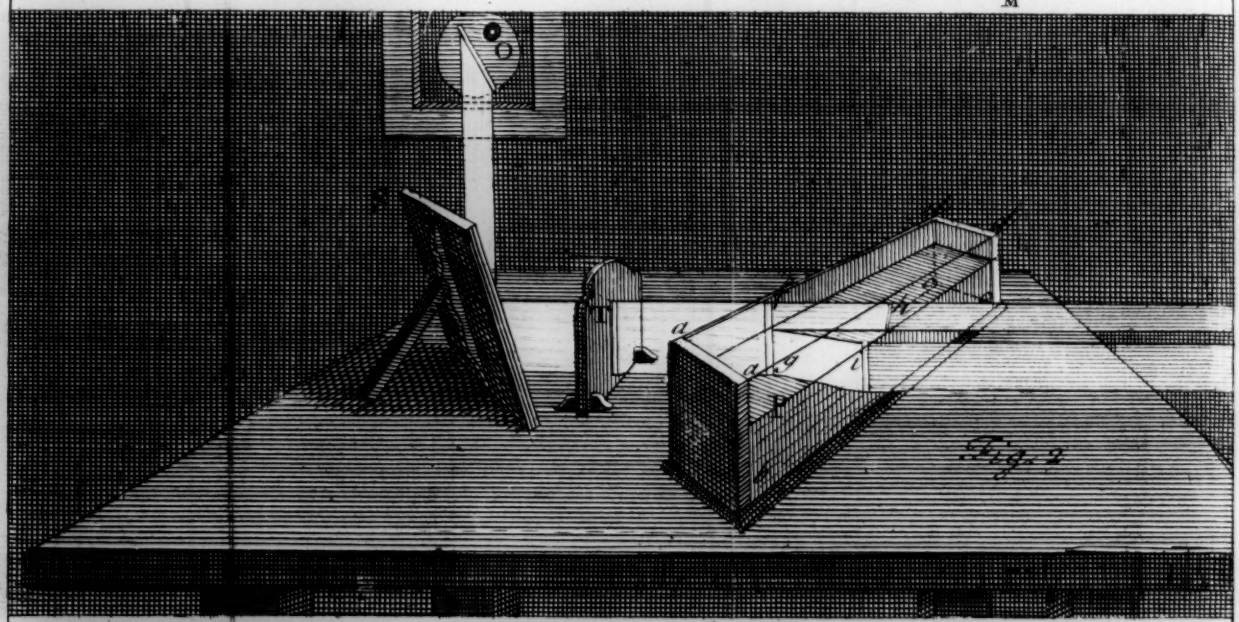


Fig. 2.

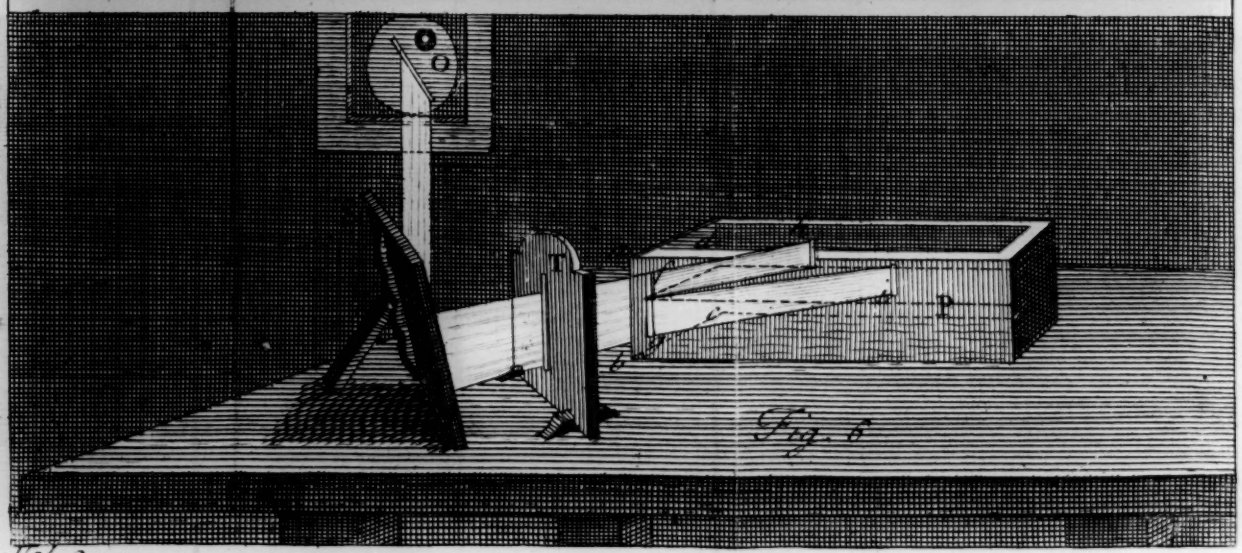


Fig. 6.

If parallel Rays paſs out of any Medium into another of different Denſity, they will alſo be parallel after Refraction: Becauſe they are all equally inflected; for, in all this Chapter, we ſpeak of Mediums ſeparated by a Plain Surface. 653

Let X *and* Z *be two Mediums, the laſt more rare, and the other more denſe, ſeparated by the Plane* E S, (*Plate* V. *Fig.* 1.) *from the Point* R C, *let there proceed the divergent Rays* P C, R *o*, R *n*, *and enter into the denſer Medium:* Let one of them be R C, perpendicular to the Surface E S; this laſt is not turn'd out of the Way *, but continues its Motion along C G. The Rays R *o*, R *n*, are refracted towards Perpendiculars, which are conceiv'd to fall upon the Surface E S in the Points *o* and *n**. *Theſe Rays are moved in the denſer Medium, as if they all proceeded from the imaginary Focus r, which is farther diſtant from the Surface than* R, *if the Rays are not too much ſcattered*; which yet is not to be underſtood Mathematically; for, by a Point, we underſtand a ſmall Space, ſuch as is otherwiſe call'd a Phyſical Point. 654 * 629 * 624

To demonſtrate this Propoſition, we muſt conſider, that the Angle R *o* C, is the Complement of the Angle of Incidence to a right Angle; and, that the Angle *r o* C is alſo the Complement of the Angle of Refraction to a right Angle; and therefore that the Lines R *o*, *r o*, are the Secants of the Complements of the Angles of Incidence and Refraction, ſuppoſing the Semidiameter to be *o* C; between which Secants, there is a conſtant Proportion *. In the ſmall Divergence R *o* and R C, as alſo *r o* and *r* C, they do not ſenſibly differ, and, between R C and *r* C, the Ratio is always conſtant; that is, *r* is fixed as well as R, tho the Inclination of the * 641 639.

the Ray be chang'd: And therefore R*n* is refracted along *n* A, as if it had proceeded from *r*.

655 *If the Rays are too much diſpers'd*, this Demonſtration will not ſerve, and the Place of Concourſe *r* cannot be taken for a Point: In this Caſe *a little Circle muſt be imagin'd* there, *into which all the Rays concur, which will be the greater, the greater the Angle is that the divergent Rays make.*

656 *If ſome Rays, proceeding from* R, *are not too much diſperſed, but fall very obliquely on the Surface* E S, *they will be refracted, as if they proceeded from a Point not very remote from the Point r:* As is plain from what has been ſaid.

657 *The Rays*, ſuch as A *n*, B *o*, G C, *which come converging from a denſer Medium* X *into a rarer* Z, concur ſooner than they wou'd do, if they ſhou'd
* 625 continue their Motion in a denſer Medium *, that is, *become more convergent*, and the real Focus is leſs diſtant than the imaginary one. In this Figure, the imaginary Focus is *r*, and the
* 625 real Focus R *. This Propoſition therefore is properly the Inverſe of the Propoſition of N°. 654.
* 626 and therefore * both are prov'd by the ſame Experiment.

Experiment 1. *Plate* V. *Fig.* 2.] Thro' the Ball G, which is moveable in the Window-ſhut, and has an Hole going thro' the Middle of it, let a cylindric Beam of the Sun come into the dark Room, and be reflected horizontally by the Looking-Glaſs S; let it then go through the Convex Lens of Glaſs that is fix'd in the Board or Stand T, and the Rays will meet together at R, and beyond R will move as if they proceeded from that Point; which therefore is the radiant Point.

Convex Lenſes of Glaſs are very common; we ſhall hereafter mention their Properties*, it being needleſs to do it in this Place: Now we only want a radiant Point, and it is enough to ſhew how to make it. * 691 697

Take a Trough Box, P, whoſe Side *a b c d* is of Glaſs, and let it be fill'd with Water: The Rays, which diverge from the Point R, become leſs diverging when they go into the Water.

When convergent Rays, as H D, I *p*, L *q* (*Plate* V. *Fig.* 1.) having their imaginary Focus at *f*, *go from a rarer Medium* Z *into a denſer* X, *they become leſs convergent* *, and concur in the Focus F, which is more diſtant from the Surface E S *, as appears by applying here the Demonſtration given in N°. 654. 658 * 624 * 652

Rays proceeding from the Point F, *and going out of a denſer Medium into a rarer, become more diverging*, and move as if they came from *f*, which Propoſition is the Inverſe of the foregoing, and is confirm'd by the ſame Experiment *. 659 * 626

Experiment 2. *Plate* V. *Fig.* 3.] Take the ſame Box B, as was uſed in the former Experiment; but here let in two Beams of the Sun into the dark Room thro' two Holes in the moveable Plate in the Window-ſhut; let them be both reflected horizontally, and tranſmitted thro' ſimilar convex Lenſes; thereby the Rays of the Beams will become convergent, having their Focus's at the ſame Diſtance; but if the converging Rays are made to run into the Water in the Box thro' the Side *a b c d*, they will be collected at a greater Diſtance; which will plainly appear by comparing together the Situation of the Points F in the Air, and *f* in the Water.

CHAP.

CHAP. VIII.

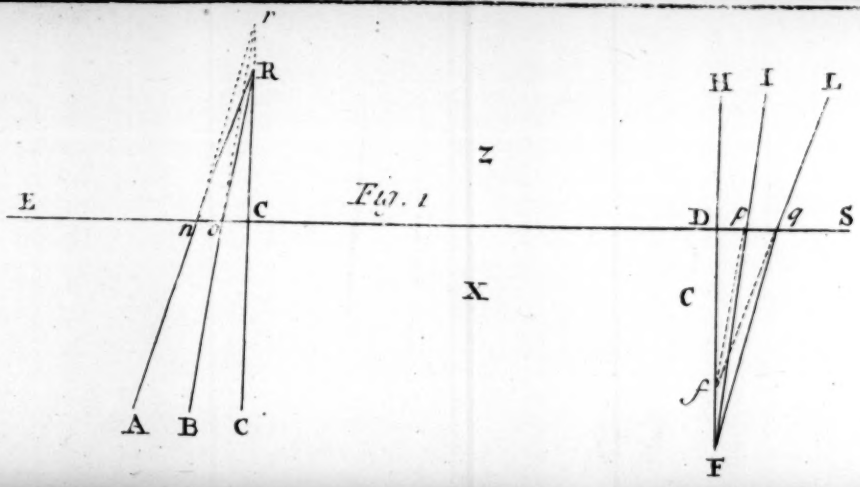
Concerning the Refraction of Light, when a ſpherical Surface ſeparates the Mediums.

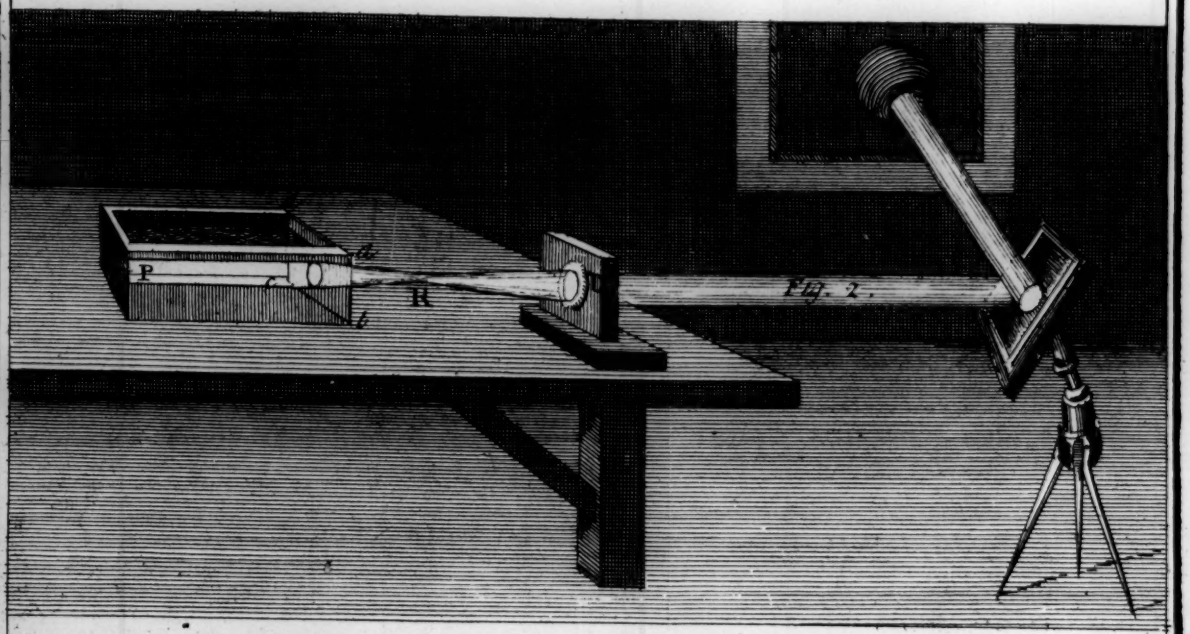
Plate VI. *Fig.* 1.] LET X and Z be Mediums differing in Denſity, the laſt the rarer, and the firſt the denſer; let them be ſeparated by the ſpherical Surface E S, whoſe Center is C, and whoſe Convexity is towards the rarer Medium.

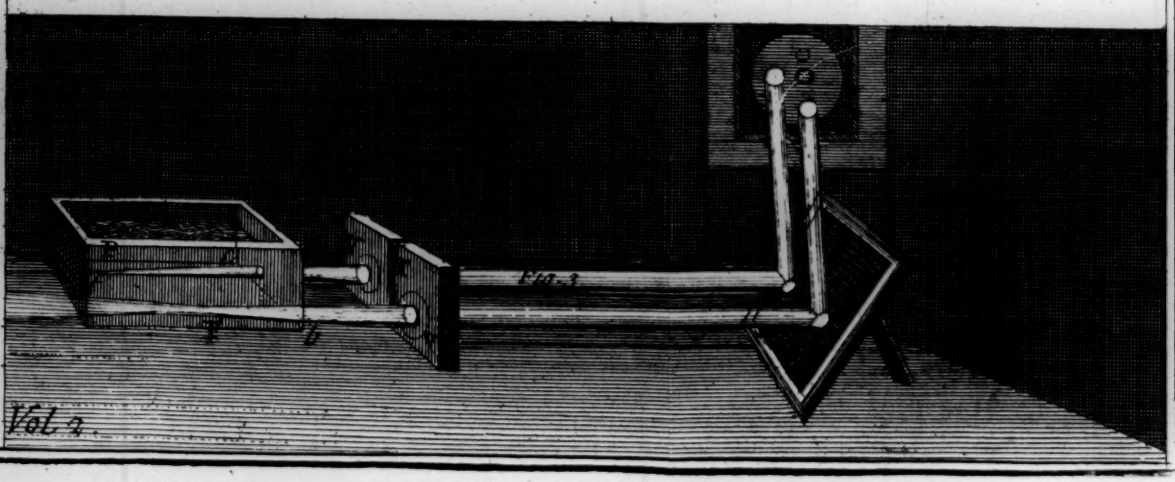
660 To begin, by examining the moſt ſimple Caſe; *Let us ſuppoſe parallel Rays*, as B O and A *n*, *going out of a rarer into a denſer Medium, and falling upon a convex Surface*, ſuch as we have juſt deſcrib'd; let one of them be B O, which, being continu'd, goes thro' the Center, and falls perpendicularly upon the Surface E S; and there-
* 629 fore is not turn'd out of the right Line *. All *the Rays, which are not too diſtant* from that Ray, come nearer to it by the Refraction of the denſer Medium, and *are collected into one Point* F: As for Example; Let A *n* be a Ray which is refracted along *n* F; thro' the Point *n* draw to the Center C the Semidiameter C *n*, and let it be continu'd to *p*; as this Line is perpendicular to the Surface which ſeparates the Mediums, the Angle of Incidence is A *n p*, which is equal to the Angle *n* C O; the Angle of Refraction is C *n* F. If the Arc *n* O be a very ſmall one, theſe Angles are as their Sines, whoſe Ratio is
* 639 conſtant *. Therefore theſe Angles *n* C O and C *n* F are increas'd and diminiſh'd in the ſame Ratio, as long as their Difference, which the Angle *n* F O, which conſequently follows the Proprotion of the Arc *n* O, which is the Meaſure of the Angle *n* C O; as long as the Arc *n* O

does

Plate 5







Vol 2.

does not exceed 15 Degrees, the Angle *n* F O is increaſed and diminiſhed ſenſibly in the ſame Ratio, as the ſaid Arc; and therefore all the Rays, between A *n* and B O, do by their Refraction meet ſenſibly in the Point F.

Experiment 1. *Plate* VI. *Fig.* 2.] Let a cylindric Beam of the Sun, of an Inch in Diameter, made up of innumerable parallel Rays (which are ſo on Account of the Sun's immenſe Diſtance) be let into the dark Room, as in the firſt Experiment of the foregoing Chapter, and be reflected horizontally by the Looking-Glaſs S.

Fill with Water the Trough P, which is about 3 Inches high, and as wide, and one Foot long. Let it have a Glaſs V made faſt in one of its Sides: This Glaſs muſt be a Portion of a Sphere, thin, and every where of the ſame Thickneſs, ſuch as the Cryſtal of a Pocket-Watch.

The Convex Part of the Glaſs V muſt be outwards, that the Water next to it in the Trough may put on a ſpherical Surface. If the Rays above mention'd go into the Trough thro' this Glaſs, becauſe the Glaſs is thin, and has its Surfaces parallel, there is no ſenſible Change in the Motion of the Light by the Refraction of the Glaſs, and the Light enters into the Water in the ſame Manner, as if there was no Glaſs. Let the Trough be ſo diſpos'd, that one of the Rays may paſs thro' the Center of the ſpherical Surface, and the others will come nearer and nearer to it, and at laſt concur with it at F.

Plate VI. *Fig.* 3] Again let X be the denſer Medium, and Z the rarer, and let them be ſeparated by the ſpherical Surface E S, whoſe Center is at C, and whoſe Convexity is towards the rarer Medium: *From the radiant Point* R *let Rays proceed,* 661

ceed, and enter into the denſer Medium thro' the Surface above-mention'd; ſo that of thoſe Rays, that which is expreſs'd by R O, being continued, may paſs thro' the Center; this Ray is not refracted as it goes into the Water, and all the reſt of the Rays come towards it by the Refraction, *and when they are not too divergent are collected into one Point* as F, in the ſame Manner as was ſaid of parallel Rays; with this Difference, that the Focus F in that Caſe is more diſtant. The ſame Demonſtration will alſo ſerve here, as relates to parallel Rays, which is built upon this Foundation, that the Angle of the Incidence increaſes in the ſame Ratio as the Arc *n* O, which does alſo obtain here, when the ſaid Arc does not exceed 15 Degrees. Let R*n* be a Ray of Light, and from the Center C thro' *n* draw C *n p*: The Angle R *n p* will be the Angle of Incidence; let it be divided into two Parts by the Line *n q*, parallel to the Line R O C; the Part *p n q* is equal to the Angle *n* CO, which is meaſur'd by the Arc *n* O, and which therefore follows the ſame Proportion as that Arc; and which alſo the Angle *n* R O (if it be very ſmall) does follow, and is equal to the ſecond Part of the Angle of Incidence, which alſo does wholly increaſe and diminiſh in the ſame Ratio, as the Arc *n* O; for the Ratio which holds in reſpect of every Part, taken ſingly, will alſo hold in reſpect of the Whole.

662 The ſame Demonſtration may be applied to any diverging or converging Rays, which in any Caſe are refracted in paſſing thro' a ſpherical Surface; and which (as appears by this Demonſtration) when they diverge but little, have their Focus real, or imaginary, or run parallel. It is enough to have obſerv'd this in general.

The

The Focus F *of the Rays, that come from* R, *goes farther off when* R *is brought nearer; and ſo on the contrary.* For the radiant Point being brought nearer, if the Point *n* remains the ſame, the Angle of Incidence is increas'd; and as it increaſes, ſo does alſo the Angle of Refraction F *n* C, and *n* F interſects R C at a greater Diſtance.

Experiment 2. *Plate* VI. *Fig.* 4.] This Experiment differs from the foregoing only in this, that a Cylindric Beam of the Sun, reflected horizontally, muſt be tranſmitted thro' the Convex Lens in the Board T, as was done in the Experiments of the foregoing Chapters, to form the radiant Point R, from which the Rays, going forward, diverging, are collected in the Water at a greater Diſtance, than if they had been parallel.

As you move the Board T, the Point R alſo changes its Place: If this Point is farther off from the Surface that ſeparates the Mediums, F falls nearer to it: On the contrary, if R be nearer, F is farther off.

The radiant Point may be brought ſo near to the 664
Surface above-mention'd, that the Focus will recede to an infinite Diſtance; that is, *that the refracted Rays will run parallel.*

Experiment 3. *Plate* VI. *Fig.* 5.] Things being diſpos'd as in the former Experiment; by removing the Board T, let R be brought nearer to the Trough; and it may eaſily be ſo diſpos'd, as to make the refracted Rays become parallel.

Experiment 4. *Plate* VII. *Fig.* 1.] Now if the 665
Experiment be repeated, *bringing nearer* to the Trough *the radiant Point* R, *the refracted Rays will become divergent; but they will diverge leſs than the*

666 *the incident Rays. If the Rays, which out of a rarer enter into a denſer Medium thro' a convex Surface, be converging and directed towards the Center of that ſpherical Surface, they will ſuffer no Re-*
* 629 *fraction* *. *But if they be directed towards another*
667 *Point*, ſince they are refracted towards the Per-
* 624 pendicular*, they will be ſo inflected, that the Focus of theſe converging Rays will always be between the Center of the Surface which ſeparates the Mediums (to which all the Perpendiculars are directed) and the Point to which the incident Rays tend. *That is, if the imaginary Focus of the incident Rays be at a leſs Diſtance than the Center, the refracted Rays will be leſs converging: But if this imaginary Focus be beyond the Center, the refracted Rays will be more converging.*

Experiment 5. *Plate* VII. *Fig.* 2.] Every Thing being in the ſame Manner, as in the former Experiments, it is eaſy to confirm theſe Propoſitions by Experiments; for the Board T may be ſo diſpos'd, that the convergent Rays ſhall enter the Water, ſo as to have their imaginary Focus at any Diſtance in it.

668 From what has been ſaid hitherto it is eaſy to determine what happens *in a contrary Motion*
* 626 *of the Rays** ; that is, the Motion of the Rays from a denſer into a rarer Medium, *the convex Surface remaining towards the rarer Medium.*

Parallel Rays, after Refraction, concur in a
* 644 *Focus* *:

669 *The Rays that come from a radiant Point meet*
* 661 alſo *in a* Point or *Focus* *, and as that Point is brought near, the Focus goes farther off; and
* 663 ſo the reverſe on the contrary*.

670 *The radiant Point may be ſo placed, as that* the Focus ſhall fly out to an infinite Diſtance; that
* 660 is, *the Rays will become parallel**.

If

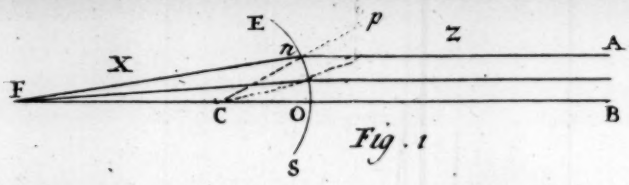


Fig. 1

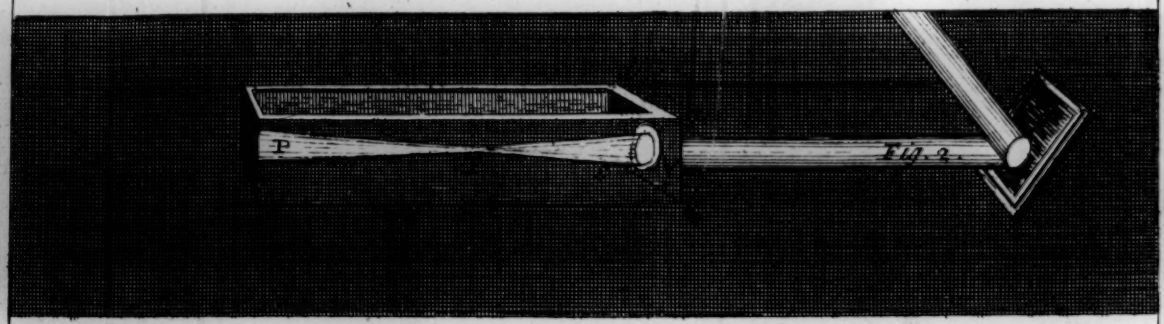


Fig. 2.

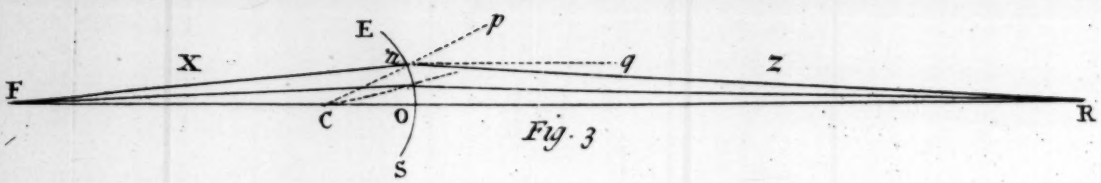


Fig. 3

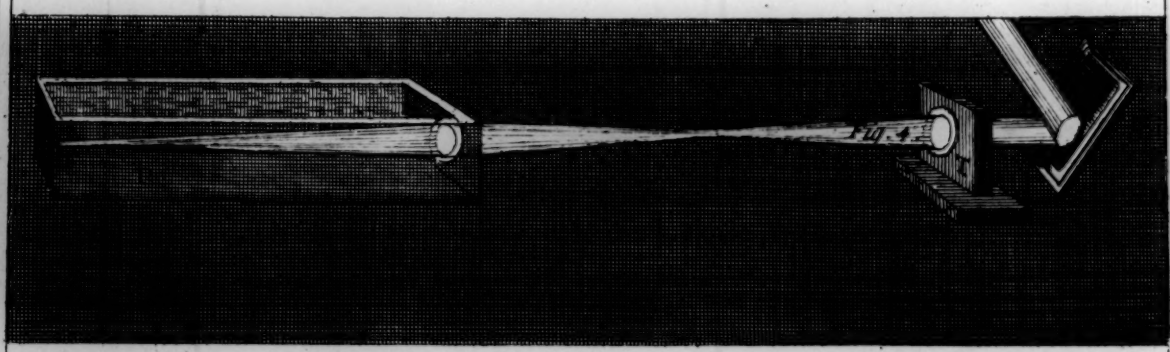


Fig. 4.

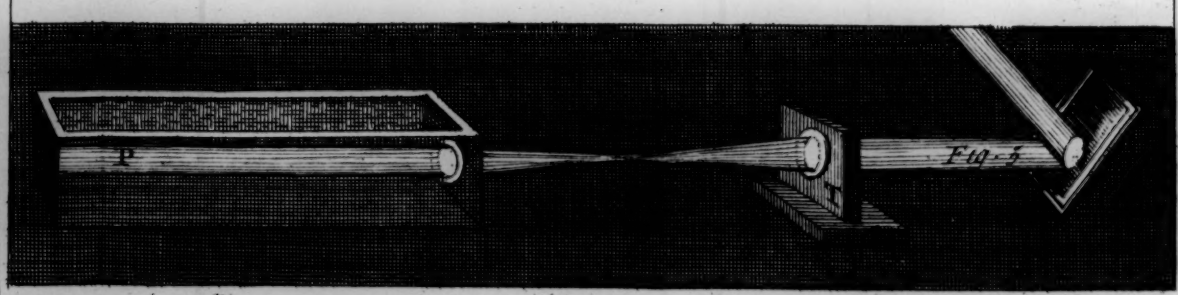


Fig. 5

If the radiant Point be brought nearer, the re- 671
fracted Rays will diverge; they *will diverge leſs than the incident Rays, if the radiant Point be more diſtant from the Surface than the Center**. * 667

But *if the radiant Point be between the Surface* 672
and the Center, the refracted Rays will be more divergent *. * 667

If the Rays are convergent, they become more con- 673
vergent in every Caſe, which follows from the Refraction being made fromwards the Perpendicular*, and which may be alſo deduc'd from N°. * 625
665.

Plate VII. *Fig.* 3.] *Let us* again *ſuppoſe the Rays* 674
to go out of the rarer Medium Z *into the denſer* X, *and that the Hollow or Concave of the ſpherical Surface* E S, *which ſeparates the Mediums, is towards the rarer Medium.* If the Rays be *parallel*, as B O, A *n*, B O, which goes thro' the Center C of the Surface E S, will not be refracted; but A *n* is refracted towards the Perpendicular C *p* along *n* G *, and, being continued towards Z, * 624
interſects B C O at *f*, which is alſo true in reſpect of the *Rays between* B O and A *n**; thoſe Rays * 662
therefore *become divergent*, having their imaginary Focus *f* in the rarer Medium.

Experiment 6. *Plate* VII. *Fig.* 4.] This Experiment differs from the firſt of this Chapter, only in this, that the Glaſs V has its Concavity towards the Air, the Trough P being in all other Reſpects the ſame; in this Caſe the Rays of the cylindric Beam diverge in the Water.

If Rays come from a radiant Point in C B, *which* 675
is beyond C (*Plate* VII. *Fig.* 3.) the Angle of Incidence A *n* C is diminiſh'd, and therefore alſo the Angle of Refraction G *n p* grows leſs; that is, *the refracted Rays become more diverging*, and the

646 imaginary Focus *f* comes nearer to C *; till by the radiant Point coming nearer, at length it coincides with the imaginary Focus at C; for in 629 that Caſe the Rays undergo no Refraction *.

676 If the radiant Point comes nearer between C and O, the imaginary Focus is farther from O than the radiant Point, for it is always between that Point and C, by reaſon of the Angles of Re- 624 fraction being leſs than thoſe of Incidence *.

Experiment 7.] Things being, as in the former Experiment; if you uſe the Board, with the Convex Lens in it, to form a radiant Point, the Experiments proving theſe Propoſitions may be eaſily made.

677 *If the Rays are converging, and the Point of Concourſe be in the denſer Mediums, near the Surface which ſeparates the Medium, the refracted Rays* will alſo *converge*, but *leſs than the incident Rays.*

678 If the imaginary Focus of the incident Rays recedes more and more from O, that is, *if they converge leſs, the refracted Rays will alſo converge leſs; until, by the receding of the imaginary Focus, the Rays become parallel.*

679 *If the imaginary Focus recedes yet farther, the refracted Rays become divergent.*

Experiment 8. *Plate* VII. *Fig.* 5.] Here the Board muſt be ſo plac'd in reſpect of the Trough, that the Rays may enter the Water converging; and the Phænomena above-mention'd may be ſeen, according as you remove the ſaid Board.

680 Rays which *from a denſer go into a rarer Medium, the concave Surface being towards this laſt*, are almoſt ſubject to the ſame Laws.

* 678 *Parallel Rays by Refraction become divergent* *.
626

681 *If they proceed from a radiant Point, they be-*
* 677 *come more divergent* *.

And

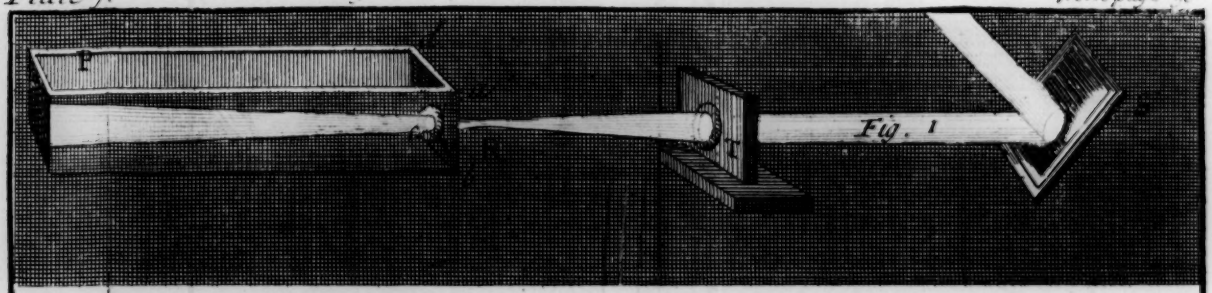


Fig. 1

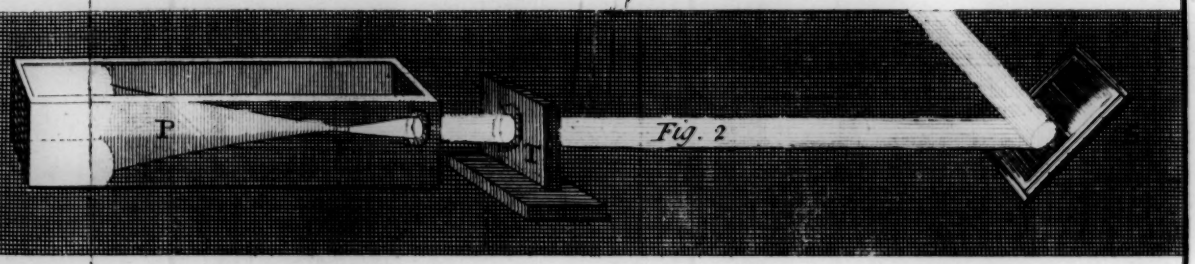


Fig. 2

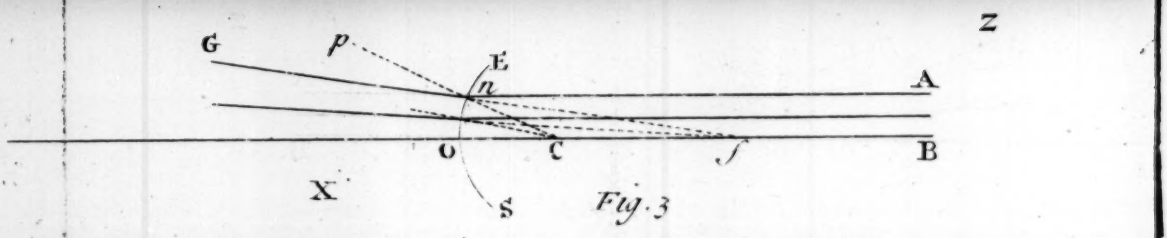


Fig. 3

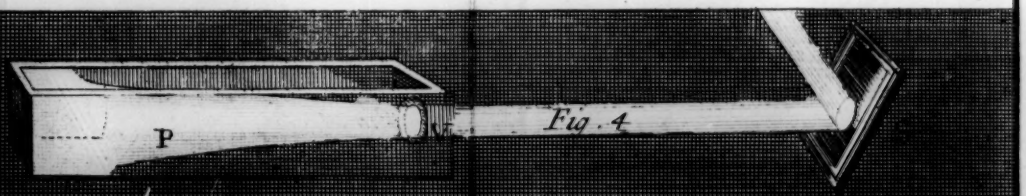


Fig. 4

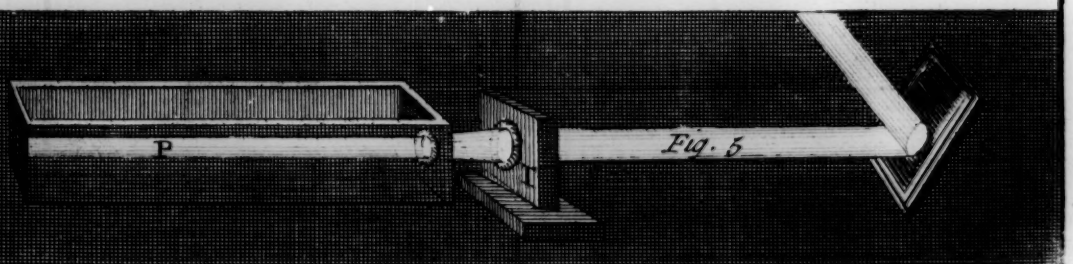


Fig. 5

And they diverge ſtill more and more, as the radi- 682
ant Point is brought nearer *. * 678

Converging Rays, which tend to the Center of 683
the ſpherical Surface, undergo no Change *. * 629

If they converge more or leſs, the imaginary Fo- 684
cus of the incident Rays is always between the Cen-
ter of the Surface, which ſeparates the Mediums, 685
and the Focus of the refracted Rays, * *which may* * 675,
recede in infinitum, *ſo as to make the refracted* 676
Rays become parallel *. * 674

We have hitherto conſider'd ſuch Rays as are but little inclin'd to the Surface which ſeparates the Mediums; for we have mention'd ſuch incident Rays as diverge but little, and one of which is perpendicular to the Surface that ſeparates the Mediums. *The ſame Propoſitions hold* 686
good in oblique Rays, yet *in that Caſe all the Rays are inflected,* which does not happen ſo in direct ones; for the Ray which is perpendicular to the Surface is not inflected. Oblique Rays alſo undergo a greater Refraction, that is, *they are more inflected either to or from each other,* 687
than direct ones, ſuppoſing the Circumſtances the ſame.

Plate VIII. *Fig.* 1.] Let Z be a rarer, and X a denſer Medium, E S the Surface ſeparating the Mediums, and having its Center at C; and the parallel Rays A *n*, B *m* will come together at F. The Rays that proceed from the radiant Point R will concur at F.

Plate VIII. *Fig.* 2.] If the Surface be turn'd ſo as to have its Concavity towards the rarer Medium, the parallel Rays A *n* and B *m* will have their imaginary Focus at *f*; but its Diſtance from the Surface E S, as alſo that of the above-mention'd Foci F and *f* in the *Figure* 1. is leſs, than if the Rays were direct.

688 *All the Points of a lucid Body are radiant Points, and have each their particular Focus*, which ſerves to explain the following Experiment, made to confirm what has been ſaid of the oblique Rays.

Experiment 9. *Plate* VIII. *Fig.* 3.] Take the Trough P mention'd in the firſt Experiment, and fill it with Water; let the Glaſs V be all cover'd, but a circular Part in the Middle of about half an Inch; have in the Trough a moveable white Plane T. If the Candle A be ſet at the Diſtance of 3 or 4 Foot from the Trough, let the Plane T be mov'd backward and forward in the Water, and when it is come to the Diſtance of the Foci of the Flame A, that Flame will appear exactly repreſented on that Plane, all the Foci forming a Picture. And this holds good, whether the Rays from the Candle fall obliquely or directly upon the Glaſs V, only that when the Rays are oblique (the Diſtance of the Candle A remaining the ſame) the Diſtance of the Plane T from V muſt be leſs. In this Caſe alſo the Candle and the Glaſs V will not be in the ſame right Line as the Repreſentation of it, as it happens when the Rays are direct, by which the Propoſition of N°. 686. is confirm'd.

689 *The Candle is repreſented inverted*, becauſe the Rays, which proceed from different Points, interſect one another as they go thro' V, as may be plainly ſeen by looking at the firſt Figure. For which Reaſon, if there are two Candles, as A and B, the Repreſentation of the laſt will be at *b*, and that of the firſt at *a*.

690 *All the Changes that happen in Light*, which we have taken Notice of in this Chapter, *are ſo much the more ſenſible, as the Surface ſeparating the Mediums is* more curve; that is, *a Part of a leſſer Sphere.*

CHAP.

CHAP. IX.

Concerning the Motion of Light thro' a more denſe Medium. Where we ſhall take notice of the Properties of Lenſes.

691 THE Uſe of Glaſſes is common, they are more denſe than Air, and the Rays out of Air paſs thro' the Glaſs into Air again. According to the ſeveral Surfaces that terminate the Glaſs, Light undergoes different Changes as it moves in it; which to determine, the Glaſſes, or any Mediums encompaſs'd with a rarer Medium, and terminated with different Surfaces, muſt be examin'd. *If we conſider only plane and ſpherical Surfaces, there are ſix Sorts.*

The Medium may be plane or flat on both Sides. 2. Plane on the one Side and convex on the other. 3. Convex on both Sides. 4. Plane on one Side and concave on the other. 5. Concave on both Sides. 6. *Laſtly*, It may be terminated with a concave Surface on one Side, and a convex one on the other.

DEFINITION I.

692 If the Glaſs be made uſe of, and is not very thick, Glaſſes, whoſe Figure is mention'd in the laſt five Caſes, are call'd *Lenſes of Glaſs.*

In the ſecond and third Caſe, a Lens is ſaid to be convex; and if we diſtinguiſh thoſe two Caſes, in the ſecond it is call'd *plano*-convex. And ſo in the fourth Caſe, it is ſaid to be *plano*-concave; tho both this Caſe, and the fifth, is generally referr'd to concave Lenſes. But a *concavo*-convex Lens is referr'd to the concave or convex Lenſes, according as the one or the other Surface is predominant; and that is ſaid

to be predominant which is moſt curve; that is, which is a Portion of a leſs Sphere.

DEFINITION II.

693 *In every Lens, or Medium, terminated in any Manner above deſcribed, a right Line, which is perpendicular to the two Surfaces, is call'd the* Axis. When both Surfaces are ſpherical, the Axes goes thro' both their Centers; but if one of them be plane, it falls perpendicularly upon that, and goes thro the Center of the other.

694 In the Paſſage of Light thro' a Medium, terminated by two plane Surfaces, *the Direction of* * 628 *the Rays is not changed* *; which is the Caſe *in plane Glaſſes.*

695 *It is the Property of all Sorts of convex Lenſes, that the Rays in their Paſſage thro' them are inflected towards one another; ſo much the more, as* 696 *the Convexity is greater: And ſo concave ones, that the Rays are deflected from one another, according as the Concavity is greater.* For the Direction of * 694 the Rays thro' a plane Glaſs is not changed; * but, by inflecting one or both Surfaces, another Direction is given to the Rays: There are more inflected towards the Axis of the Lens, by reaſon of the Convexity of the Surface of the Glaſs, and, by making the Surface concave, they are deflected from the Axis; as is plain in every Caſe, by comparing the Inflection in the plane Surface that is perpendicular to the Axis, with the Inflection in the ſpherical Surface at any Diſtance from the Axis. And the Difference of their Inflexions, that is, the Change of the Direction of the Rays, increaſes, as their Diſtance from the Axes does; and it is to be obſerv'd in every Direction of the Rays, as well in oblique Rays, as in direct: but *the Changes are greater in oblique Rays*, becauſe the Angles of Incidence are greater. From which 697 we deduce the following Properties of Lenſes.

That

That *parallel Rays, by paſſing thro' a convex Lens, concur in a Focus.* 698

That *diverging Rays either diverge leſs, or run parallel, or laſtly, converge; in which Caſe, the radiant Point receding, the Focus comes nearer, and ſo on the contrary:* But this is the Caſe, when the radiant Point is farther diſtant from the Lens than the Focus of parallel Rays. 699

Laſtly, That *converging Rays converge more, when the Light emerges out of the Lens.* 700

The ſame Things are obſervable in oblique Rays; concerning which it is to be noted, that the Diſtances of the Foci of the emerging Rays, are leſs than in the direct, and the other Changes more ſenſible.* 701 * 697

All theſe ſame Things may be deduced from examining the double Refraction in the Entrance and Emerſion of Light. And this double Refraction is viſible in every Caſe, by the following Experiments; by which the aforeſaid Properties of convex Lenſes are confirm'd.

Plate VIII. *Fig.* 4.] Take ſeveral Boxes like P, with Water in them, and thro' which Light is tranſmitted thro' the Glaſſes V and V, which are placed in the oppoſite Sides of the Box, and are diſtant from one another about one Inch. Theſe Glaſſes are thin; in the Box which repreſents a convex Lens, on each Side there is placed one, like that of the firſt Experiment of the former Chapter, which are ſo diſpoſed as to have their Convexities without the Box. When a *plano*-convex Lens is to be repreſented, on one Side there is a plane Glaſs. A *concavo*-convex Lens is repreſented by two ſpherical Glaſſes, that are Portions of different Spheres, and the Convexity of the Portion of the greater Sphere, muſt be turn'd towards the Inſide of the Box. 702

Whilſt the Light paſſes thro' theſe Boxes, the Changes of the Light are viſible to the Eye in

its Entrance into, and Emerſion out of a denſer Medium, and by the Aſſiſtance of theſe, all Things, relating to convex Lenſes, are clearly demonſtrable.

Experiment 1.] *Ex. gr.* Let P be one of the fore-mentioned Boxes, with the ſpherical Glaſſes V, V, the Convexities being placed outwards; let it be fill'd with Water; in a dark Room let a cylindric Beam of the Sun be horizontally reflected from the Looking-Glaſs S; let this Beam enter the Box; the parallel Rays, of which it is form'd, will be inflected towards one another, and will converge; at their Emerſion on the other Side, they will converge more, and concur in F. Experiments may be made of the incident Rays, which diverge or converge, by uſing the Board with the convex Lens, as in the Experiments of the former Chapter.

Every Point of a lucid Body, as was ſaid be-
* 688 fore, is a radiant Point, * and being placed at a due Diſtance from a convex Lens, every one has
* 698 its Focus. *

Experiment 2.] Let a lighted Candle be removed from a convex Lens beyond the Focus of parallel Rays; at the oppoſite Part of the Lens, upon a white Plane, by the Foci of the Points of the Flame, it will be repreſented; and this Repreſentation will be inverted, by reaſon of the Interſection of the Rays in their Paſſage thro' the Glaſs.

703 *Convex Lenſes are alſo burning Glaſſes*, becauſe
* 698 they collect the Rays of * the Sun, which, upon the Account of the immenſe Diſtance of the Sun, are eſteem'd as parallel. But Rays united in a Focus, (by reaſon that the Fire, that was before diſperſed, is now collected, and by reaſon

Plate 8. *front page 56.*

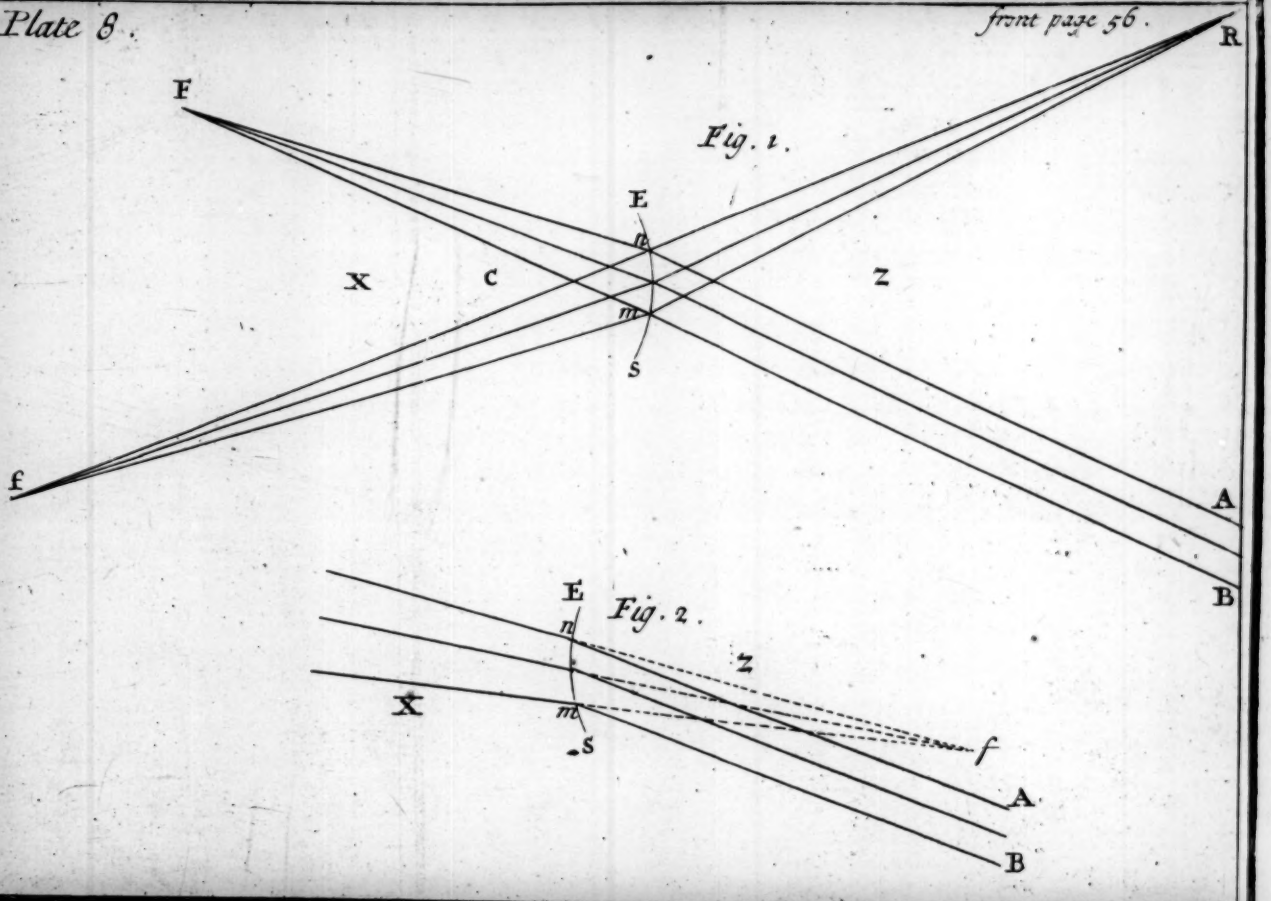


Fig. 1.

Fig. 2.

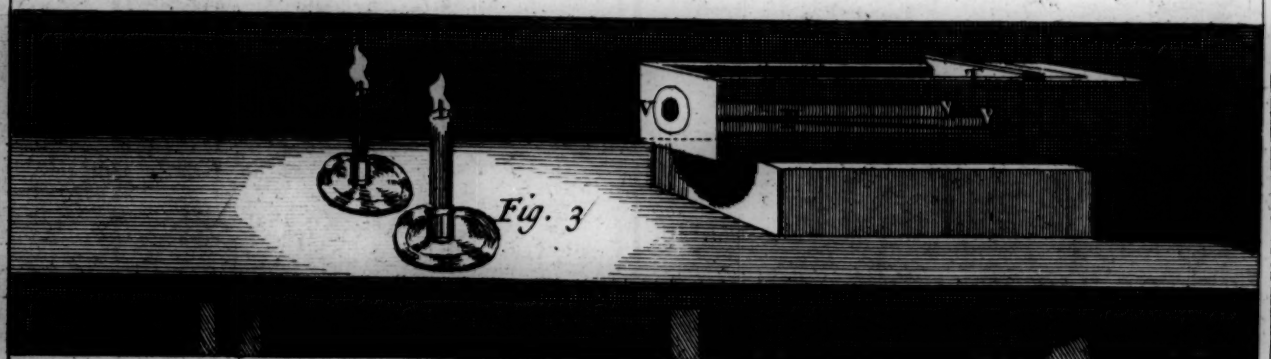


Fig. 3.

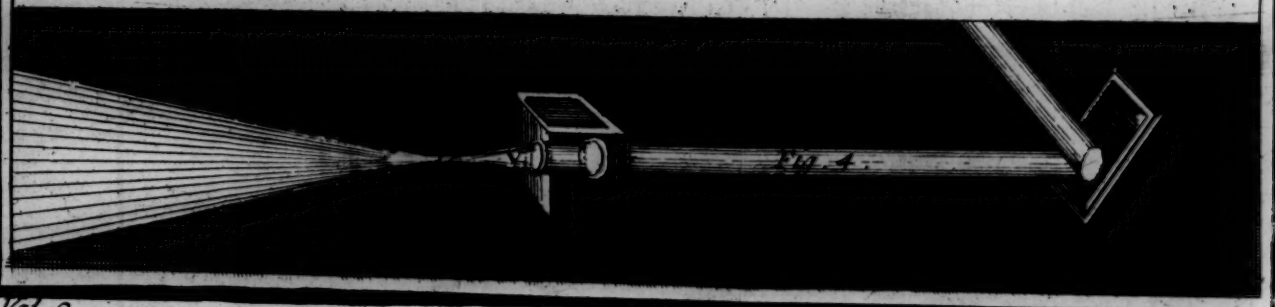
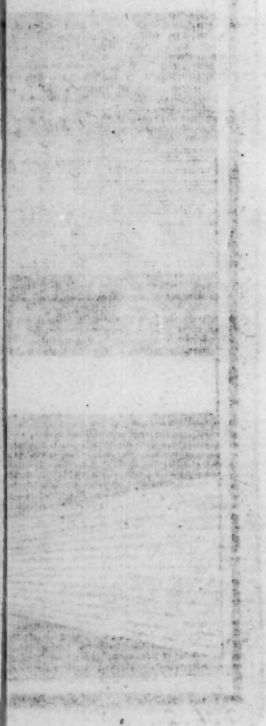


Fig. 4.

Vol. 2.



ſon of the Motion of the Fire according to various Directions,) do burn vehemently.

Experiment 3.] Take a convex Lens of any Magnitude, ler it be ſo expoſed to the Rays of the Sun, that the Axis of the Lens may be in the Direction of the Rays; if any combuſtible Body be placed in the Focus of the Sun's Rays, it will burn.

When, by reaſon of the Magnitude of the Lens, the Rays are not exactly enough collected, before they come to the Focus, they muſt be tranſmitted thro' another convex Lens that is leſs, by which they will be reduced into a ſmaller Compaſs, ſo as to burn more violently.

As for concave Lenſes, and their Properties, they may be eaſily deduced from * what has been ſaid. * 696

Parallel Rays become diverging, by paſſing thro' a concave Lens. 704

Diverging Rays diverge the more. 705

Converging Rays either converge the leſs, or become parallel, or (as it happens in ſuch as converge leſs) *go out from the Lens diverging.* 706

All which Things happen to oblique as well as direct Rays, but more ſenſibly in the firſt. * 707 * 697

Plate IX. *Fig.* 1.] Boxes, to repreſent the Effects of concave Lenſes, are made in the ſame Manner as thoſe that repreſent the Effects of convex ones.* The Difference is only in the Poſition of the Glaſſes: In the firſt Box the Concavities of the two ſpherical Glaſſes V, V, are outwards. In the ſecond, inſtead of one of thoſe Glaſſes, you have a plane Glaſs. In the third. you have two ſpherical Glaſſes, but Sections of different Spheres; the Section of the greater Sphere has its Convexity outwards, and the other its Convexity inwards. 708 * 702

Expe-

Experiment 4.] Parallel Rays of the Sun, reflected horizontally in a dark Chamber by the Looking-Glaſs S, muſt be tranſmitted thro' the Box P, which is full of Water, and repreſents a Lens concave on both Sides: As they go into the Box they will begin to diverge, and as they go out they will diverge more.

The remaining Experiments, relating to concave Lenſes, are made in the ſame Manner, as has been ſaid, in reſpect of convex Lenſes.

CHAP. X.

Of Viſion; where we ſhall ſpeak of the Make of the Eye.

THE Properties and Laws of the Refraction of Light, that we have explain'd, are of wonderful Uſe in repreſenting Objects to our Mind.

By theſe Laws, the Objects are beautifully painted in their proper Colours in the Bottom of the Eye; and this Picture, as I ſhall ſay here-
*716 after, * is the Occaſion of the Ideas which are excited in our Minds concerning the Things that we ſee.

How this Picture is form'd in the Eye, cannot be explain'd, without examining a new Property of Light; namely, its Diviſibility, which is paſt our Comprehenſion.

DEFINITION.

709 *A Body that is not lucid, and intercepts the Light, is ſaid to be* opaque.

710 *Several* among all the opaque *Bodies*, when exactly poliſh'd (except perfectly black Bodies, if

there are any ſuch) have the Property of dividing Light; for they *reflect the Light, ſo that the Rays from every Point*, being ſtruck back, are divided, and *recede every Way*, ſo that *all the ſingle Points of the Body become as it were radiant Points*, from which Light goes every Way.

Whence we deduce a Method of painting Ob- 711
jects upon a white Plane; for all the Points of the enlighten'd Body, from which the Rays come upon a convex Lens, have their Focus of the other Side of the Lens.* The Foci of diſtant * 699
Objects, tho not exactly, are ſenſibly at the ſame Diſtance from the Lens; thoſe Objects may by theſe Foci be repreſented in the ſame Place; which Repreſentation is inverted, (by reaſon of the Interſection of the Rays as they go thro' the Glaſs,) and ſenſible in a dark Place, in which Light comes in no Way but thro' the Lens, and only that Light by which the Objects are repreſented.

This will do wherever the Lens is placed, and in Reſpect of all the Points of Objects, enlighten'd by Rays of Light, from which right Lines without Interruption may be drawn to the Lens; in this Manner the above-mention'd Diviſibility in Light may be proved, and the Aptneſs that Bodies, that reflect Light, have to divide it.

Experiment 1. *Plate* IX. *Fig.* 2.] Make an Hole in a dark Place, over-againſt ſeveral Objects that are at leaſt 50 Foot off or farther. Let the Hole be V, and let it have a convex Lens in it that collects parallel Rays at the Diſtance of about 4 or 5 Feet; if a white Plane be placed behind the Lens a little farther from it than that Diſtance, all the Objects above-mention'd will be painted upon it in very beautiful Colours. It is to be obſerv'd, that the Lens muſt be placed in a Po-

a Poſition parallel to the Plane; and that by moving the Lens or the Plane, the Diſtance muſt be found at which the Objects are repreſented moſt exactly.

This Repreſentation of Objects has great Affinity with that by which the Objects, that we ſee, are repreſented in the Bottom of the Eye, as will appear from the Make of the Eye.

712 The Figure of the Eye, when taken out of the Head, is nearly ſpherical; only the Fore-part is ſomething more convex than the reſt.

The Section of the Eye is repreſented *Plate* IX. *Fig.* 3.

The Part A A, which is moſt convex, is tranſparent, and call'd the *Tunica Cornea*.

The whole Covering of the Eye, except the *Cornea*, is call'd the *Sclerotica*, B A A B.

That Part of the *Sclerotica*, which is next to the *Cornea*, is call'd *the Adnata*, or *White of the Eye*.

Behind the *Cornea*, on the Inſide, is a Coat call'd the *Uvea*, which has in its Middle an Hole *pp*, call'd the *Pupil*.

The Uvea is made up of concentric circular Fibres, interſected at right Angles by ſtrait Fibres. If the firſt are ſwell'd, the laſt are relax'd, and the Pupil is leſſened or contracted; and a contrary Motion of the Fibres increaſes or widens it.

In the Middle of the Eye, but nearer the Fore-part, there is a tranſparent ſoft Body C C, like a convex Lens, whoſt Hind-part is more convex than the Fore-part. It is call'd *the Cryſtalline Humour*. Its Axis coincides with the Axis of the Eye, that goes thro' the Centers of the Pupil and the whole Eye.

This cryſtalline Humour is ſuſtain'd by ſmall Fibres or Threads, which are fix'd to all the Points of its Circumference, and likewiſe to the

Inſide of the Eye: They are inflected in the Form of an Arc, and every one of them is a Muſcle; they are call'd the *Ligamenta Ciliaria*, and two of them are repreſented by *l* C, *l* C. They all cohere to one another, and, together with the Cryſtalline, make a Separation in the Eye, and divide it into two Cavities, one forwards *p p*, and the other backwards S S.

The Cavity, that is forwards, is fill'd with a Liquor like Water, call'd the *Aqueous Humour*.

The hind Cavity is fill'd with a tranſparent Humour, nearly of the ſame Denſity as the Aqueous Humour, but not ſo fluid, call the *Vitreous Humour*.

The hind Surface of the Eye within is lined with a Coat call'd the *Choroides*, which is again cover'd with a thin Membrane call'd the *Retina*.

At the back Part of the Bulb of the Eye, a little on one ſide, is the Optic Nerve N N ſo join'd to the Eye, that the Eye itſelf is, as it were, an Expanſion of the Optic Nerve; for the expanded Coats of the Nerve form the Choroides and Sclerotica, and the Fibres, which make up the Retina, concurring, make the Marrow of the Nerve.

The Eye is moved in the Head by ſeveral Muſcles inſerted in the Sclerotica; but we ſhall not treat of them here: As we only conſider the Eye with reſpect to the Motion of Light, we purpoſely forbear to take Notice of any Thing elſe.

Rays that proceed from any Point, and enter the Eye thro' the Pupil, go out of a rarer into a denſer Medium thro' a ſpherical Surface; and therefore *if that Point be at a due Diſtance from the Eye*, the Rays *after Refraction will converge*; * in the ſame Manner as in the Experiment of N°. 663. (*Plate* VI. *Fig.* 4.) in which the Glaſs V repreſents the tranſparent Cornea of the Eye, whilſt the Water 731 * 661

in

in the Trough is inſtead of the aqueous Humour; and therefore, *ſuppoſing only the Cornea and the*
714 *aqueous Humour, there will be in the Eye an in-*
*710, *verted Picture of the Objects.* *
711

Experiment 2. *Plate* IX. *Fig.* 4.] Let P be the Trough above-mention'd full of Water, and ſet in a dark Place, which has an Hole about half an Inch wide, ſo diſpoſed towards enlighten'd Objects at a certain Diſtance, that one may ſee them thro' the Hole; let the Glaſs V of the Trough be applied to this Hole, and upon the white Plane T you will have an inverted Picture of the Objects: By moving the Plane backwards and forwards, you will find the Place where the Picture is moſt diſtinct.

If the abovemention'd Picture, which we have imitated in this Experiment, was to be made in the Eye, it would be at too great a Diſtance from the Cornea, and beyond the Bottom of the Eye; and therefore this Diſtance is diminiſh'd
715 *by Help of the Cryſtalline Humour*, which is denſer, but encompaſs'd with rarer Mediums; for the Rays, converging in the aqueous Humour, paſs thro' the cryſtalline into the vitreous Humour; that is, out of a rare Medium thro' a denſer, (which is terminated by two ſpherical convex Surfaces) into a rare Medium again; by
*700 which Motion the Rays converge ſtill more; * and therefore they concur ſooner, and *the Picture above-mentioned falls within the Eye.*

716 *The Objects which*, as we have explain'd, *are repreſented in the Bottom of the Eye, are painted upon the Retina; and by the Motion of Light the ſmall Fibres, of which the Retina is made up, are agitated; by which Agitation, the* Ideas *of the Objects, painted in the Eye, are excited in the Mind.* The Connexion between the *Ideas* and the Motions by which they

they are excited, is unknown to us, * as we ſaid before: In determining the Cauſes of Senſations, we can go no farther than the Agitation of the Nerves. * 502

The more exact the Picture above deſcribed is, the more diſtinct will the Objects appear. When the Rays, coming from the ſame Point, are not exactly united upon the Retina, its Picture is not a Point, but a Spot, which is confounded with the Pictures of the neighbouring Points; in which Caſe the *Viſion is confuſed.* 717 718

But when, *according to the different Diſtance of the radiant Point,* its Focus is brought nearer, or removed farther off, * *it is neceſſary that there ſhould be a Change in the Eye, leſt* the Place, in which the Picture is exact, ſhould fall ſhort of, or beyond the Retina, and ſo *the Viſion ſhould be confuſed.* 719 * 663

But it is very difficult to determine what this Change is, and Philoſophers are divided in their Opinions about it: I ſhall only obſerve in general, that *it is not very probable that the Figure of the whole Eye is changed, in order to put back or bring forward the Retina*; and therefore we muſt expect to find this Change within the Eye. 720

For if the Figure of the Eye was changed, as this Change muſt be equally neceſſary in all Animals, the Eyes of all Animals would undergo the ſame Changes; for the ſame natural Effects cannot have different Cauſes. Now in the Whale the Sclerotica is too hard to be ſubject to any Alteration of Figure. Beſides, if there was ſuch a Change in the whole Eye, it would ariſe from the external Preſſure of the Muſcles, which would be different in different Poſitions of the Eye, and only regular in one Situation of it.

If now we examine the Eye within, it will appear neceſſary that there ſhould be a Change in the Cryſtalline; which by changing its Place

or

or Figure in the Eye, will produce the desired Effect; for the Rays that fall upon the Retina, before they are united, will be made to unite just upon the Retina, if the Crystalline becomes
* 695 more convex, * or if (its Figure remaining the same) it be brought forwards towards the Cornea.

721 That *the Position of the Crystalline Humour is* easily *changed, and* that *it is brought nearer to, or farther from the Retina*, its Axis remaining the same, is plain, because the ciliary Ligaments are muscular: When these Muscles are swell'd, and become shorter, the Hollow which their Inflection makes at C*l*, C*l*, becomes less; by which means the vitreous Humour is compress'd, and therefore it presses upon the Crystalline, and pushes it forwards farther from the Retina; which is necessary when we look at near Ob-
* 663 jects.*

699 From an Experiment, that we shall hereafter
753 mention, it has been demonstrated, that there is another Change in the Eye that acts contrary to this; and we shall shew what is the Occasion of it. The second Change is also to be re-
622 ferr'd to the Crystalline; which (*when it is drawn by the ciliary Ligaments, to make it recede from the Bottom of the Eye*) *becomes also flatter, and therefore it must recede farther than if its Figure was unchangeable*; that is, the Change becomes more sensible; which we shall shew to
* 730 be of Use.*

These Changes in the Eye have their Limits, for which Reason also *Objects appear only distinct*
724 *within certain Limits, which are different Distances*
725 *according to the Difference of People's Eyes; and very often in the same Man, both Eyes have not the same Limits*; which is almost of the same Use, as if the Limits of both Eyes were more distinct from one

one another: For one may ſee an Object diſtinctly enough with only one Eye. In ſome Perſons alſo the neareſt Limit of one Eye is farther off than the fartheſt of the other: In which Caſe near Objects and diſtant Objects are ſeen diſtinctly, but the intermediate ones appear confuſed.

The Picture in the Bottom of the Eye, as has been ſaid, * is inverted; whence a Queſtion ariſes, why we ſee Objects erect? To which we anſwer by asking another Queſtion; Whether it is more eaſy to conceive the Connexion between an Idea in the Mind, and an erect Figure, than an inverted one? We confeſs, that we have no Notion of that Connexion in either Caſe: But Experience teaches us, that there is a Connexion between an inverted Picture in the Eye, and the Idea of an erect Object; and further than this we do not know. 726 * 714

If we look at the ſame Object with both Eyes, it will appear ſingle; but this happens only when the Object is painted in correſpondent Points of each Retina; which probably happens from the meeting of the Optic Nerves. For it is obſerv'd in all Animals, which ſee the ſame Object with both Eyes, that the Optic Nerves meet and ſeparate again before they go to the Brain; but in Animals which ſee different Objects with each Eye, the Optic Nerves go ſeparately from the Eyes to the Brain. 727

Only one Point at a Time can be ſeen diſtinctly, namely, that which is repreſented in the Axis of the Eye; if we look at one Point with both Eyes, we muſt ſo direct the Eyes, that their Axes continued ſhall meet in that Point; which happens when we have our Eyes intent upon any Point. 728

By this Direction of the Axes we judge of the Diſtance of Objects; for the Situation of the Eyes alter according as the Axes make a different Angle, which Angle depends upon the Diſtance of the Object: Whence it happens, that without perceiving when we do it, by Uſe we get a Habit of judging of the Diſtance of
729 Objects *by the Direction of the Axes*; which is ſenſible to us, becauſe it depends upon the Motion of the Eye, that we feel. Therefore we may ſee the Uſe of having two Eyes placed at a certain Diſtance from one another; *as long as this Diſtance of the Eyes bears a ſenſible Proportion to the Diſtance of the Objects, we can judge of it pretty certainly.*

730 *We can alſo judge of leſſer Diſtances with one*
*721 *Eye alone*; becauſe in the Variation of a ſmall
723 Diſtance, the Change in the Eye is ſenſible.*

731 *In great Diſtances*, if we look at known Objects, *we judge from the apparent Magnitude and the Colour.*

732 *It is impoſſible to judge of very great Diſtances, except the ſame Objects be ſeen from different Places.*

733 *The apparent Magnitude of an Object depends* upon the Bigneſs of the Picture in the Bottom of the Eye, which Picture depends *upon the Angle under which an Object is ſeen*, that is, the Angle which is form'd by Lines drawn from the Extremities of the Object to the Eye.

734 *This* apparent *Magnitude* is to be diſtinguiſh'd from the Magnitude *which our Mind attributes to the Object that we ſee*, which laſt is founded upon the Judgment, whoſe Foundation is not in the Appearance alone. Every Body knows that the Object appears the leſs according as it is more diſtant; whence it happens, that, *according to the greater Diſtance of the Object*, if it be known, the apparent Magnitude of the Object *is increas'd*

in

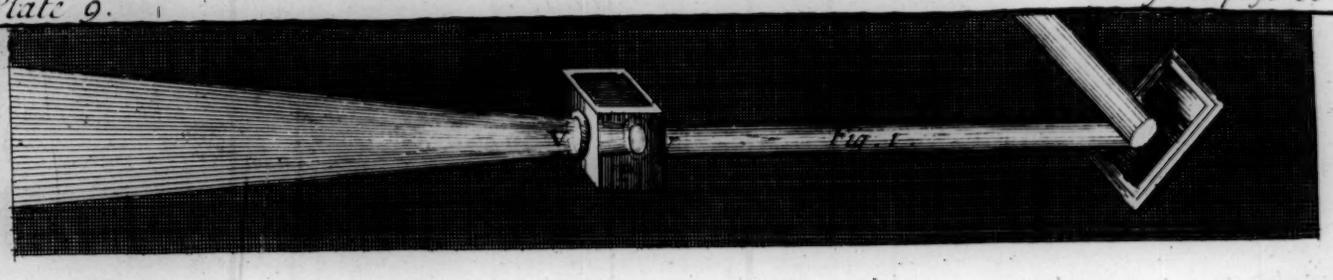


Fig. 1

Fig. 2

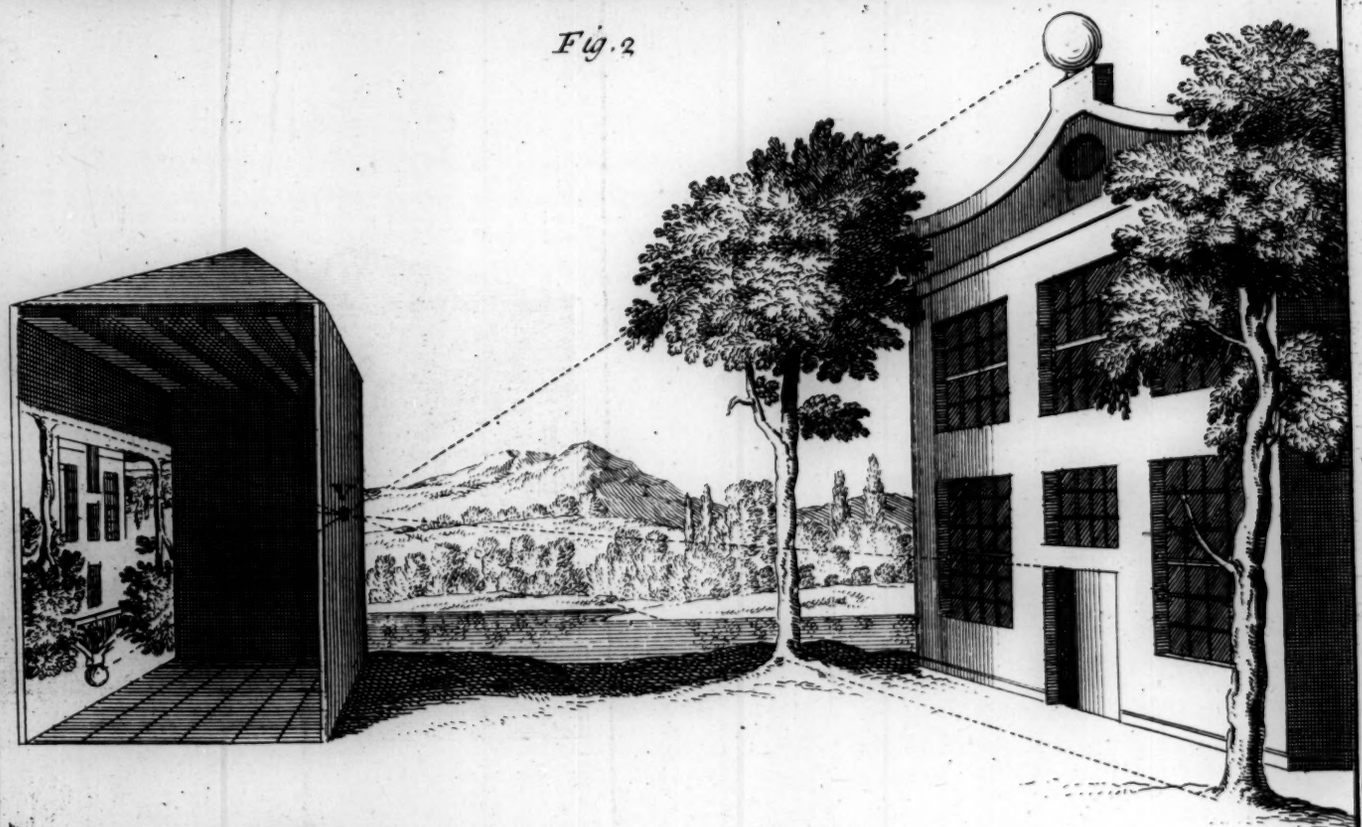


Fig. 4.

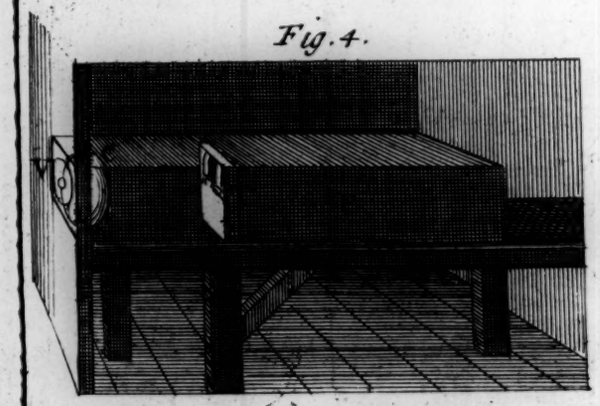


Fig. 3.

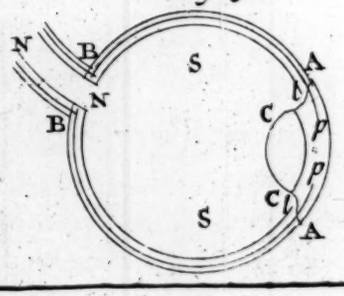
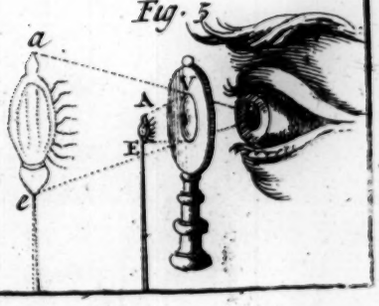


Fig. 5



in the Judgment that our Mind makes of it, which we do without any Attention to it. Therefore the ſame Object at the ſame Diſtance appears of a different Magnitude, if we judge differently of the Diſtance.

We have a remarkable Example of this in reſpect of the Sun and Moon, which appear greater 735
when near the Horizon, than at a greater Height; tho, as is known to Aſtronomers, the Picture of the Sun in the Bottom of the Eye is the ſame in both Caſes, and that of the Moon is leſs when it appears nearer the Horizon; we cannot judge of the Diſtance in either Caſe, * but it appears * 734
greater near the Horizon, by reaſon of the Interpoſition of the Fields and Part of the Heavens. If we ſee the Bodies above-mention'd thro' a Tube, this apparent Diſtance vaniſhes, as alſo the Magnitude which is deduc'd from it. From our Childhood upwards, and ſo continually, we join the Idea of Diſtance with the Increaſe of apparent Magnitude, (which is neceſſary for making a true Judgment concerning the Magnitude) whereby the Ideas are ſo cloſely join'd, that they cannot be ſeparated, not even in thoſe Caſes, in which we know that they lead us into Error. Logicians teach us, how many Errors are to be attributed to Ideas ſo join'd.

CHAP. XI.

Of Viſion thro' Glaſſes, and how to correct ſome Defects of the Eyes.

AN Object is viſible, becauſe all its Points 736
are as it were radiant Points; * therefore * 713
a *Point appears in that Place from whence diverging* 714
Rays are emitted. 715

737 *If Rays inflected any how enter the Eye diverging, the viſible Point will be in the imaginary Focus of the Rays*; for the Rays enter the Eye exactly in the ſame Manner that Rays would do that came directly from that Focus; and to have them unite upon the Retina, the ſame Situation of the Cryſtalline is requiſite; ſo that, in reſpect to a Spectator, it is no Matter whether thoſe Rays, after Refraction, or theſe directly enter the Eye; and there will be the ſame Motion in the Eye, when * 719, 730 it fits itſelf for diſtinct Viſions. *

738 *A Point appears the more enlightened, the greater Number of Rays coming from it enter the Eye.*

739 *When Objects are ſeen thro' a plane Glaſs terminated with parallel Surfaces, they appear to be nearer than when ſeen with the naked Eye.* Let A (*Plate* X. *Fig.* 1.) be a viſible Point; the Rays, going from it and entring the Eye, are between A *b* and A *b*; theſe, being refracted in the Glaſs V V, move along *b c*, *b c*, and go out thro' *c d*, *c d*, * 628 which are parallel to the Lines A *b*, A *b*: * now becauſe *b c*, *b c*, are refracted towards the Perpen- * 624 dicular, * *c d*, *c d*, fall between *b* A and *b* A; that is, they interſect at *a*, which is nearer than A; therefore the imaginary Focus of the Rays which enter the Eye is at *a*, in which the Point A ap- * 737 pears to be. *

740 *That Point* alſo *appears to be more enlightened, when ſeen thro' the Glaſs above-mentioned.* For all the Rays between A *b* and A *b* enter the Pupil between *d* and *d*; but as the Lines A *b*, A *b*, are parallel to the Lines *c d*, *c d*, and theſe are between thoſe, A *b* and A *b* being continued would fall beyond *d* and *d*; therefore if the Glaſs was taken away, the Rays, which now enter the Pupil, would take up a greater Space, and therefore would not all enter the Eye.

Plate

Plate X. *Fig.* 2.] *The apparent Magnitude of an Object is increaſed by the Interpoſition of a plane Glaſs*; the Object A E is ſeen by the naked Eye under the Angle A *d* E; but if you uſe the Glaſs V V, by reaſon of the Refraction thro' A *b c d* and E *b c d*, it will be ſeen under the Angle *c d c*, which is greater than the laſt. 741 742 *But yet the Object is not greater in Proportion to the increaſed apparent Magnitude*; * for it appears to be at a leſs Diſtance.* * 734 * 739

The Increaſe of apparent Magnitude is ſo much the greater, as is the Difference of the Angles A *d* E and *c d c*; whoſe Difference *increaſes* as the Interſections of the Lines A *d* with *b c*, and E *d* with *b c*, come nearer to the Points *b* and *b*; which obtains *as the Object is brought* nearer to the Glaſs; and therefore it is the greateſt of all, when the Object touches the Glaſs; which ſhews that Objects, even in the Glaſs itſelf, muſt appear magnified. 743

And in general, *the Eye being placed in a rarer Medium, the Object that is ſeen in a denſer Medium appears bigger, and is alſo brought nearer by the Refraction.** This is every Day confirm'd by Experience, when we look at Objects in the Water. 744 * 659

Let there be *a Point* A *ſeen thro' a convex Lens* V V, (*Plate* X. *Fig.* 3.) and the Rays A *b*, A *b*, at *c d*, *c d*, will go out more diverging, as if they came from *a*; * therefore that Point *appears to be at a greater Diſtance.** *It appears alſo more enlightened*; for the Rays come nearer to each other as they go thro' the Glaſs, * and are alſo reduced into a leſs Space, wherefore a greater Number of them muſt enter the Pupil. 745 * 699 * 737 746 * 695

The apparent Magnitude of an Object is alſo increaſed; that is, the *Object ſeen thro' a convex Glaſs* is ſeen under a great Angle, which ap- 747

pears from a Sight of the Figure; the Object A E, ſeen with the naked Eye, is ſeen under the Angle A *d* E, (*Plate* X. *Fig.* 4. and 5.) but now it is ſeen under the Angle *c d c*, which is greater; (in *Fig.* 4.) the Rays A *b*, E *b*, which are convergent, converge more as they go out of the
* 700 Lens; * or diverging (as in *Fig.* 5.) they come
* 699 to the Eye converging.* Therefore the Object *appears magnified*, both from the Appearance of
* 745 it being farther, * and its Magnitude being in-
* 734 creas'd; * and therefore *the Magnitude, that we*
748 *attribute to an Object, does not follow the ſame Proportion as the apparent Magnitude*; for which Reaſon we ſhall not delay Time in Demonſtrations about it: But we ſhall obſerve in general,

749 That *the Angle, under which an Object is ſeen thro' a convex Glaſs, diminiſhes as the Eye recedes from the Glaſs; whilſt the Object is not more diſtant from the Glaſs than the Point in which parallel Rays are collected: But if the Object is farther off, the apparent Magnitude is increaſed as the Eye recedes.*

750 After the ſame Manner, *if the Eye be between the Glaſs and the Focus of parallel Rays, the Angle abovemention'd is diminiſhed as the Object is farther removed; the Eye being placed at a greater Diſtance, the ſame Angle is increaſed as the Object is farther removed*; in which laſt Caſe the Object may be ſo far removed, as not to be viſible beyond the
* 754 Glaſs, as will be ſaid anon.*

Alſo in thoſe Caſes in which Objects are viſible, they do not always appear diſtinctly.

751 For, *that a Point may appear diſtinct, it is required that the Rays that proceed from a Point ſhould*
* 736 *enter the Eye diverging, * and that the imaginary*
* 727 *Focus of thoſe Rays, in reſpect of the Spectator,*
724 *ſhould be within the Limits of diſtinct Viſion.**

752 If the Object be removed beyond the Focus of parallel Rays, the Rays flowing from a Point of

of the Object, enter the Eye converging; * which Caſe is impoſſible to the naked Eye: In this the Viſion is always confuſed, and the Eye diſpoſes itſelf ſo as to have the Viſion the leaſt confuſed that may be; from this Diſpoſition we judge of the Diſtance, as we do in every Caſe in which we judge of it with only one Eye.* * 699 * 730

753 But this Diſtance does not always appear to be the ſame; whence may be deduced what is ſaid of the Change of the Figure of the Cryſtalline.* For if, ſuppoſing the Cryſtalline moveable, its Figure be unchangeable, in every Situation of the Object and the Eye, in which the Rays, coming converging from a Point, enter the Eye, there will be the leaſt Confuſion, if the Cryſtalline comes back towards the Retina as far as may be; ſo that in every Caſe there would be the ſame Diſpoſition of the Eye, and the ſame Judgment concerning the Diſtance; which, as has been ſaid, is contrary to Experience: But if it becomes flatter as it recedes from the Retina, there will be Changes in the Eye, which agree with the ſeveral Judgments made of the Diſtance in different Situations of the Object and the Eye. * 722

754 *If in the laſt Caſe, in which Rays, coming from a Point converge, the Eye be ſo removed, that the Rays unite before they come to the Eye,* in all the Points in which the Rays concur, there will be radiant Points; which are the Foci of all the Points of the Object, by which the Object is repreſented inverted upon a white Plane; * and which are viſible Points in reſpect of the Eye, to which the Rays can come after their Interſection.* In that Caſe *the Object appears inverted*, becauſe we don't ſee the Object itſelf, but its Repreſentation behind the Glaſs, which we have ſaid to be inverted.* * 711 * 736 * 711

755 We have ſaid that the Caſe is impoſſible to the naked Eye, in which the Rays, coming from a Point, enter the Eye converging; and therefore ſuch Viſion is always confuſed, becauſe the Conſtruction of the Eye cannot adapt itſelf to an impoſſible Caſe: Yet ſometimes, but rarely, even in that Caſe, the Objects are ſeen diſtinctly; which, as it is occaſioned by ſuch a Defect of the Eye as takes away all diſtinct Viſion from the naked Eye, I did not think proper to take Notice of ſuch Exceptions of the general Rule.

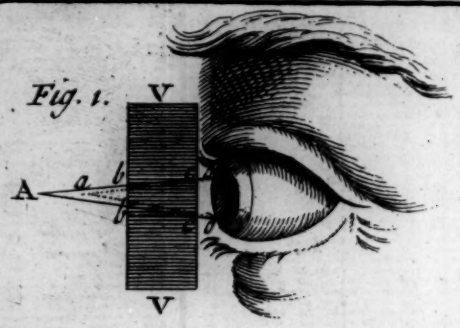
756 *The Fault of the Eyes of a great many old Men* is, that they can ſee none but diſtant Objects diſtinctly, thoſe that are near appearing confuſed to them; which Defect *is corrected by the Interpoſition of a convex Lens.* The Rays, which flow from a Point which is near, concur beyond the Retina; paſſing thro' a convex Glaſs, they will diverge leſs as they enter the Eye, and ſo concur ſooner in the Eye; that is, come to the Eye as if they flow'd from a remote Point, ſuch as is ſeen diſtinctly by an old Man.

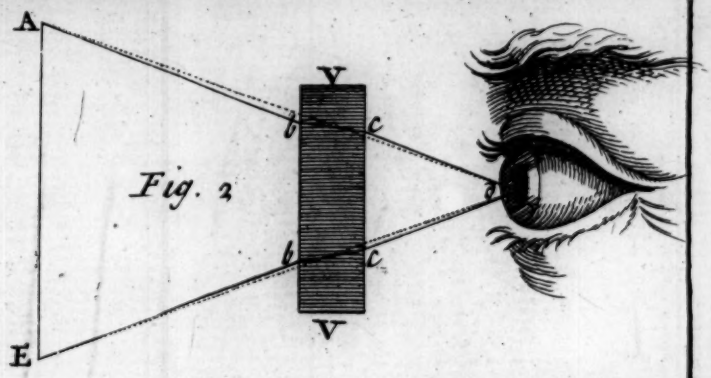
757 *Thro' a concave Lens Objects appear to be nearer, leſs enlighten'd, and leſs.*

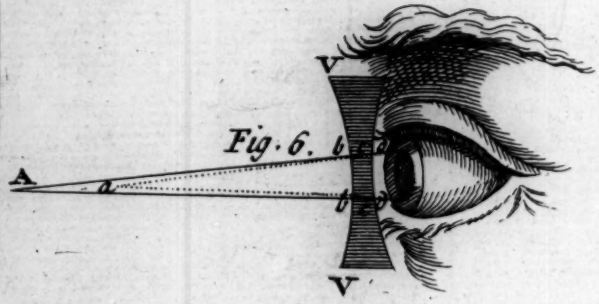
Plate X. *Fig.* 6.] The Rays A*b*, A*b*, and all that are between, going thro' a concave Lens
* 705 become more diverging, * and enter the Eye as
* 652 if they came from a Point *a*, which is leſs diſtant,*
* 737 where the Point A appears to be.*

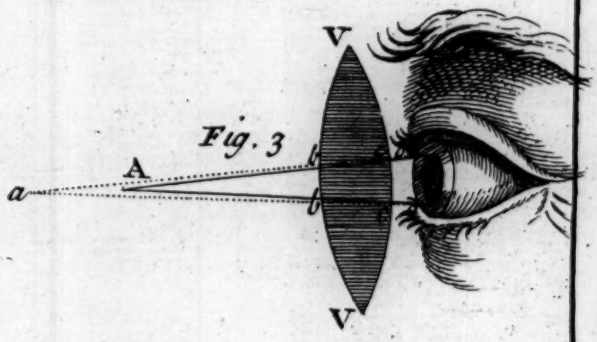
By making the Rays to diverge more, they are carried farther aſunder; and therefore fewer of them enter the Eye, which diminiſhes the
* 738 Illumination of the Point ſeen.*

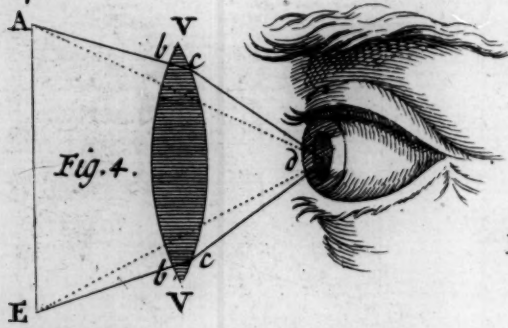
Plate X. *Fig.* 7.] The apparent Magnitude is alſo diminiſh'd, becauſe the Rays A *b*, E*b*, by which we ſee the Extremities of the Object,
* 706 come to the Eye leſs converging, * and therefore the Angle *c d c*, under which the Object is ſeen beyond

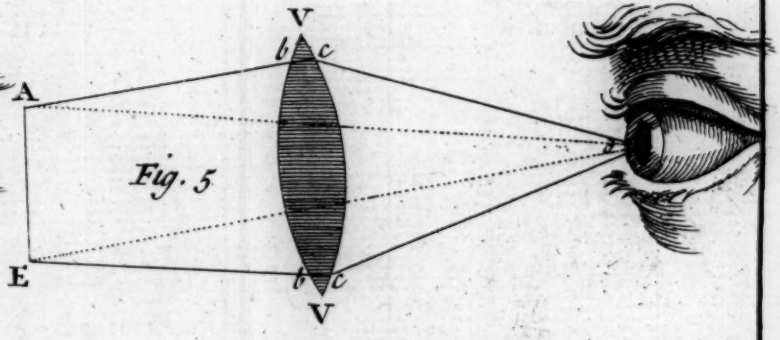

Fig. 1.
V
A
a
b
b
c
V

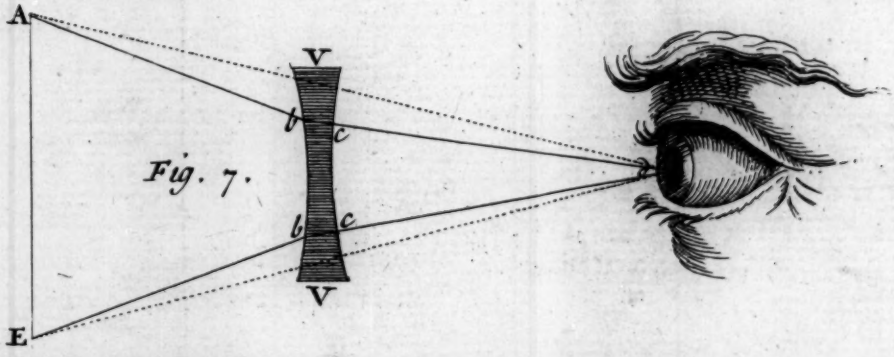

A
V
b
c
Fig. 2
b
c
V
E

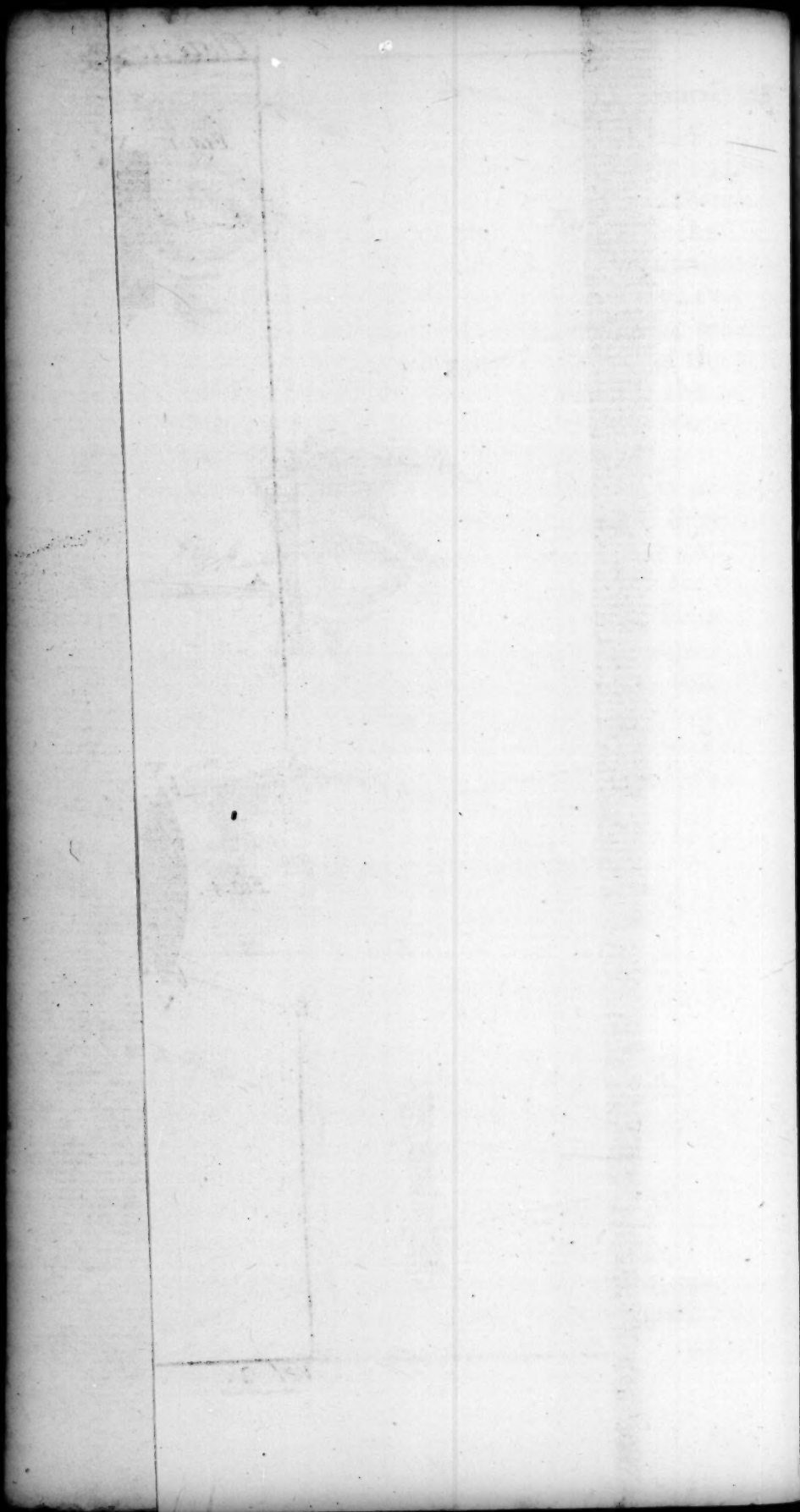

V
Fig. 6.
A
a
b
V


V
Fig. 3
A
a
b
V


A
V
b
c
Fig. 4.
b
c
V
E


V
b
c
A
Fig. 5
E
b
c
V


A
V
b
c
Fig. 7.
b
c
V
E



beyond the Lens, is leſs than the Angle A *d* E, under which it is ſeen by the naked Eye: Therefore upon account of the Diminution, both of the Diſtance and the Angle above-mention'd, the Object appears diminiſh'd.* * 734

A concave Lens is of Uſe to thoſe who ſee no Objects diſtinctly, but ſuch as are near; ſuch are call'd Myopes; thro' this Lens remote Points appear to be near, * and the Rays, which did concur before they came to the Retina, now enter the Eye more diverging, and meet upon the Retina. 758 * 757

There are Glaſſes that have one Surface plane, and the other Side is made of ſeveral plane Surfaces that make Angles one with another, (like a Diamond) thro' theſe the Rays that flow from one Point ſuffer different Refractions; and by every Surface are made to enter the Eye in a different Direction, as if they came from different Points: That is, the ſame Point forms ſeveral imaginary Foci; and therefore appears multiplied; for it is ſeen in ſeveral imaginary Foci *: which as it happens in reſpect of every Point of the Object, *thro'* ſuch *a Lens, which is a Polyhedron* (or multiplying Glaſs) *the Object appears multiplied.* * 737 759

CHAP. XII.

Of Microſcopes and Teleſcopes.

WE have ſhewn of what Uſe Glaſſes, terminated with ſpherical Surfaces, are for correcting the Defects of the Eyes of old Men and of the Short-ſighted *. How they ſerve for diſcovering the ſmalleſt Objects, and bringing the moſt diſtant (as it were) to the very Eye, is what we are now to conſider. * 756 758

We

We have ſaid that the convex Glaſſes magnify
* 747 the Objects*; which magnifying depends upon the Refraction of the Rays as they go thro' a convex Lens; whence it follows, that it is increaſed, if, in the ſame Circumſtances, the Refraction be increaſed; which Effect may be produc'd, by augmenting the Convexity of the Lens; which will be the more convex, as the Surfaces that terminate it are Segments of a leſs Sphere; which can only be had in very ſmall Glaſſes.

Definition I.

760 Such ſmall Lenſes are call'd *Microſcopes.*

761 *By a Microſcope ſmall Objects are vaſtly magnified*; by which means, Things, which wou'd be inviſible to the naked Eye, are very diſtinctly ſeen.

Definition II.

762 *The Space ſeen thro' the Microſcope, that is, the Circle in which Objects are viſible thro' the Microſcrope, is call'd the* Field of the Microſcope.

Experiment 1. *Plate* IX. *Fig.* 5.] If we look at the ſmall Object A E thro' the Microſcope V,
* 745 it will appear magnified at *a e* *.

747 There are alſo compounded Microſcopes, made up of two or three Lenſes; what Foundation they depend upon, will be ſufficiently ſhewn by explaining one of thoſe which is made up of two Lenſes.

Plate XI. *Fig.* 2.] Take a ſmall Lens that is very convex, as V V, and let the Object A E be plac'd at ſuch a Diſtance from it, that all its
* 710 Points ſhall have their Force beyond the Lens;
699 let the Object be brought ſo near, that the Foci
* 699 may be remov'd to *a e* *, and you will there have the Repreſentation of the Object, very much enlarg'd,

enlarg'd, which will be ſenſible if you receive it there upon a white Plane *. *711

Experiment 2. *Plate* XI. *Fig.* 1.] The Lens abovemention'd muſt be made laſt in the End of a Tube at V; and the other End of the Tube, which is wider, muſt be cover'd with a very thin Paper C C; the Object A E muſt be ſo plac'd, that the Foci of the Points of that Object ſhall be juſt at the Diſtance of the Paper: If then the Object be well enlighten'd, you will have its Repreſentation inverted, viſible thro' the Paper at *a e*. By moving the Object, you will have the true Poſition that brings the Repreſentation upon the Paper to be diſtinct.

Plate XI. *Fig.* 2.] All the Points of the Repreſentation *a e* are radiant Points, and therefore viſible *; which, being ſeen thro' a large Microſcrope V V, ſhews the large Repreſentation *a e* 754 at a e *; that is, the Rays coming from the Object A E, after the Refractions thro' both the Lenſes V V, V V, will enter the Eye, as if they came from an Object at *a e*. *736 *761

Therefore *thro'* ſuch *a compounded Microſcope the Object appears inverted, and much more magnified than thro' a ſingle Microſcope.* 763

Definition III, and IV.

In this Microſcope the ſmalleſt Lens, which is next to one Object, is called the Object-Glaſs, *and the other the* Eye Glaſs. 764

This laſt ought not to be too ſmall; for the Points of the Repreſentation *a b*, tho they be radiant Points, do not emit Light every Way; only the Rays, which paſs thro' the Object-Glaſs, inteſect one another in the ſeveral Points of the Repreſentation *a b*; which Repreſentation therefore will not be viſible, unleſs the Rays that go thro' the Object-Glaſs do alſo go thro' the Eye-Glaſs.

765 Glaſs. *The Field* therefore (or the Space that the Microſcope can take in) *depends upon the Magnitude of this Lens.*

The Eye alſo muſt be ſo plac'd, that all the Rays that come to the Eye-Glaſs, going thro' it, ſhall come to the Eye; which is done by placing the Eye at *d*, *the Point in which all the Rays, which come from the Center of the Object-Glaſs, and paſs thro' the Eye-Glaſs, are collected.*

Objects appear bright enough thro' Microſcopes, becauſe they are very near the Glaſs; and ſo the ſame Number of Rays paſs thro' a ſmall Lens as wou'd not paſs at a greater Diſtance, unleſs thro' a great Hole: *Yet often, where Objects are the moſt magnified, they muſt be enlighten'd by*
767 *Rays collected thro' a convex Lens and thrown upon them.*

The Aſtronomical Teleſcope much reſembles the compound Microſcope.

Definition III.

768 *Inſtruments, fitted to ſee diſtinct Objects, are call'd* Teleſcopes.

769 That which we now treat of is call'd the *Aſtronomical* Teleſcope, becauſe it is not ſo fit for ſeeing Objects upon Earth; for it repreſents them inverted: But Aſtronomers do not much regard the Poſition of the Appearance of the Object.

This Teleſcope conſiſts of two convex Lenſes, the one an Object-Glaſs, which is plac'd next to the Object, and the other an Eye-Glaſs, plac'd next to the Eye. By Help of the firſt, diſtant Objects are repreſented at a certain Diſtance be-
* 711 hind the Lens *, as near Objects are in the compound Microſcope. If this Repreſentation be obſerv'd thro' an Eye-Glaſs, it will appear enlarg'd and inverted, as we have ſaid concerning the Microſcope.

It is plain alſo, that in this Caſe, as well as in the Microſcope, the *Field depends upon the Breadth of the Eye-Glaſs*; as alſo, that *the Place of the Eye muſt be determined in the ſame Manner for the Teleſcope as for the Microſcope* *: For the Aſtronomic Teleſcope differs from the compounded Microſcope only in this, that in the Microſcope the Lenſes are more convex, and therefore leſs proper for looking at diſtant Objects, eſpecially in reſpect of Object-Glaſſes. In the Microſcope, the Object-Glaſs is more convex than the Eye-Glaſs; but the contrary obtains in the Teleſcope. 770 771 * 766

Teleſcopes cannot be too long for obſerving the Stars: But, if they are above 20 Foot long, they are of no Uſe for ſeeing Objects upon Earth; becauſe of the conſtant Trembling of the Air, which is too ſenſible in Glaſſes that magnify very much.

A ſhort *Aſtronomic Teleſcope will ſerve to ſee Objects upon Earth, by adding to it two convex Lenſes*, which are alſo call'd Eye-Glaſſes; the three Eye-Glaſſes are alike, and leſs convex than in the Aſtronomic Teleſcope, the Object-Glaſs remaining the ſame. 772

Plate XI. *Fig.* 3.] Take an Object-Glaſs V V, which repreſents a diſtant Object at *e a*; then take beſides three Eye-Glaſſes D D, D D, D D; the firſt muſt be ſo plac'd, that the Rays, coming from the Point of the Repreſentation *e a*, ſhall become parallel when they have paſs'd the Lens *; in that Caſe the Rays, which come from the middle Point of the Object-Glaſs, will be collected at G; the Second Lens muſt be ſo plac'd, that theſe Rays which are collected at G (where they interſect one another, and move as if they came from that Point) may go out parallel after they have paſs'd thro' it *; which being perform'd, the Rays coming from the Object-Glaſs to *e*, 773 * 699 * 669

and

and there interſecting and forming that Point of the Repreſentation of the Object, being refracted thro' the firſt Lens, paſs by G parallel to one another; thro' the Second Lens they are refracted
* 698 in the Direction D e, and collected at e *, ſo as to make it the Point of a new Repreſentation. In the ſame Manner the Point of a new Repreſentation correſponds to the Point a of the ſecond Repreſentation; which being alſo true concerning the intermediate Points, there will be found an erect Repreſentation of the Object at a e.

Experiment 3. *Plate* XI. *Fig.* 4.] Let three little Boards D, D, D, with Eye-Glaſſes in them, that collect parallel Rays at the Diſtance of about 5 Inches be moveable upon a Plane between two Rulers, in ſuch Manner that the three Glaſſes may be in the ſame Line as the Hole V, thro' which alone the Light enters into the Room, and in which there is an Object-Glaſs, which is fix'd in a ſhort Tube, in order to exclude all the ſide Light.

This Object Lens is ſuch as is able, at the Diſtance of 3 Feet from V, to repreſent diſtant Objects inverted at F; which Repreſentation will be viſible, if you let the Rays fall upon a
* 711 white Plane in that Place *. Five Inches farther from F, you muſt place the firſt Eye-Glaſs, and 10 Inches from that, you muſt place the Second; at *f*, which is five Inches from it, you will have an erect Repreſentation of the ſame Objects, which will alſo be viſible, if receiv'd upon a white Plane.

Plate XI. *Fig.* 3.] If the Repreſentation a e be
774 ſeen thro' a third Eye-Glaſs, ſuppoſing the Eye at *o*, in which the parallel Rays a D and a E are collected, *the Object appears magnified, brought near, and erect*; for it is ſeen under the Angle D *o* D,

D*o*D, when with the naked Eye it wou'd appear under a very ſmall Angle; it will alſo appear near, becauſe, tho it be ſeen beyond a e, yet the Diſtance, at which it appears, has no ſenſible Relation to the Diſtance of a very diſtant Object.

Experiment 4. *Plate* XI. *Fig.* 4.] Suppoſing every Thing as in the foregoing Experiment; let there be a third Eye-Glaſs plac'd 10 Inches from the Second, and 5 Inches from that a little Board, or Eye-Stop, with an Hole O; if the Eye be plac'd at O, the Object, as has been ſaid, will appear erect, magnified, and near. If the Board O be diſplac'd, that is, be brought nearer or remov'd farther off, the Field of the Teleſcope is diminiſh'd; becauſe there is but one Situation of the Eye, in which all the Rays which paſs thro' the Eye-Glaſſes can come to the Eye.

We are to take notice, that the Eye-Glaſſes, made Uſe of here, are not convex enough in reſpect of the Object Glaſs V; but they are beſt for making the 3d Experiment.

All the Points of the Object do alſo *appear more enlighten'd:* For the Rays which, coming from any Point of the ſeveral Points of the Object Glaſs, do interſect one another in a Point of the Repreſentation, by reaſon of the ſmall Diſtance of the Eye-Glaſs from that Repreſentation, are but little diſpers'd before they come to the Eye; ſo that they all go into it. And therefore the Illumination, given by the Teleſcope, is to that which is given by the naked Eye, as the Surface of the Object Glaſs, thro' which the Rays paſs, to the Surface of the Pupil.* 775 *738

One may alſo *with two Lenſes make Teleſcopes, which ſhall ſhew Objects erect, enlighten'd, and magnified.* Theſe muſt be ſhorter; for if they be above one Foot long, they become almoſt uſeleſs, 776

becauſe

becauſe their Field will be ſo ſmall; that is, they will take in ſo little of an Object.

Plate XI. *Fig.* 5.] Let V V be an Object-Glaſs, the inverted Repreſentation of a diſtant
* 711 Object will be at *e a**: The Rays are ſo intercepted by the concave Lens D D, that ſuch of them, as come from the Center of the Lens V V, are inflected as if they proceeded from the Point
* 705 *f**; by the ſame Refraction in the Rays which
* 706 concurr'd at *a*, become diverging*; having their imaginary Focus at a; which alſo happens in reſpect to all the Points of the Repreſentation *e a*, and, inſtead of it, you have an imaginary Repreſentation which is erect at a e; that is, the Rays enter the Eye as if they came from the Object plac'd at a e.

777 The Rays, in all reſpects, go out diverging from the Eye-Glaſs; and therefore *the Eye muſt be brought as near as poſſible to the Eye-Glaſs.*

778 *In this Teleſcope, the Field depends upon the Bigneſs of the Object Glaſs*; for the Rays, which from a Point come obliquely to the Center of this Lens, very often do not enter the Eye; whilſt other Rays from the ſame Point, which paſs thro' the Lens near its Circumference, do come to the Eye.

CHAP. XIII.

Of the Reflexion of Light.

WE have ſhewn that Light is reflected from opaque Bodies, and that every Point
* 710 reflects it every Way*. The Occaſion of this is the Inequality of the Surfaces, which are made up of an innumerable Quantity of ſmall Planes, which, in all ſenſible Points, are directed every

front page 80.

Fig. 1.



Fig. 2.

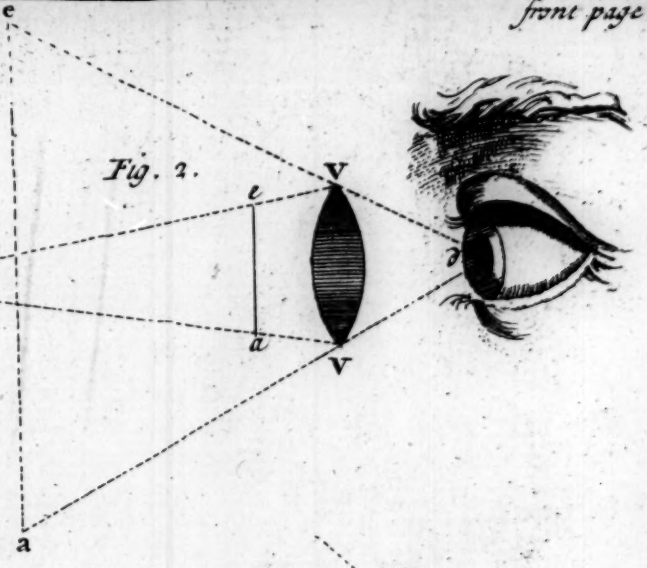


Fig. 3.

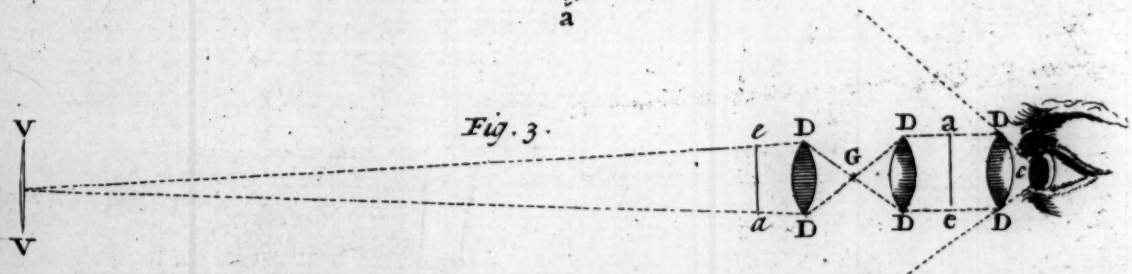


Fig. 4.

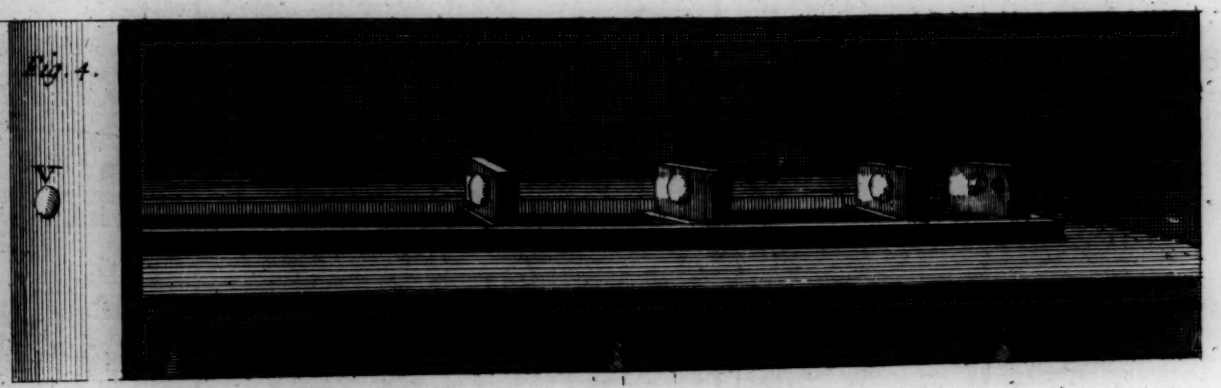
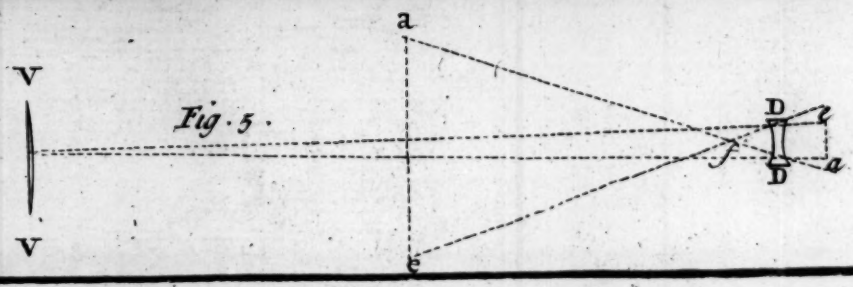


Fig. 5.





every Way; which will be eaſily conceiv'd, if we imagine a Surface cover'd with an innumerable Quantity of ſmall Hemiſpheres. That this is true, we deduce from the Reflexion of Light from a poliſh'd Surface; that is, from a Surface whoſe Inequalities are taken off; which 779
in all its Points reflects the Light only one Way, which holds in Curve as well as in plane Surfaces: Nay, from Surfaces that are not at all poliſh'd, the Light is moſtly reflected that Way, and it would be all reflected if they were poliſh'd, as daily Experience ſhews.

Plate XII. *Fig.* 2.] Let A C be a Ray of Light coming obliquely upon a plane Surface; let C O be perpendicular to this Surface, and the Rays be reflected along C B.

Definition I.

The Ray C B is call'd the *reflected Ray.* 780

Definition II.

The Angle O C B is call'd the *Angle of Re-* 781
flexion.

The reflected Ray, together with the incident 782
Ray, in the ſame Plane which is perpendicular to the reflecting Plane.

For *the Action of this Plane, by which the Light* 783
is reflected, is directed perpendicularly to a Plane, which is ſuppoſed like in all Points.

The Angle of Reflexion is equal to the Angle of 784
Incidence.

Experiment 1. *Plate* XII. *Fig.* 1.] Take a plane Looking-glaſs S, which may be ſet in any Poſition by Means of a Ball and Socket join'd to the Foot that ſuſtains it; thro' a Hole, in the Plate of Metal L, that is in the Window, let in a Sun Beam of about a Quarter of an Inch Diame-

ter into the Room; the Glaſs muſt be ſo diſpoſed that the Beam may come thro' an oblique cylindric Cavity (of the ſame Bigneſs as the Beam) made in a little upright Board T: If you turn this Board Side for Side, the reflected Ray will go thro' the ſame Cavity. This holds good, whatever the Inclination of the Cavity be, as may be demonſtrated by uſing different Boards.

By which Experiment N°. 779. is prov'd, as well as N°. 784.

785 *Plate* XII. *Fig.* 2.] *If the reflected Ray becomes the incident Ray*; that is, if the Light comes along the Line B C, it will return in the Line C A, that is, the firſt *that was the incident Ray will become the reflected Ray*; as appears from the Equality of the Angles B C O, O C A.

From this Equality of the Angles of Incidence and Reflexion, we farther deduce, that

786 *the Light, after it has fallen upon a Body, recedes from it with the ſame Force that it came upon it.*

Let the Motion along A C be reſolv'd into two

*192 Motions along A O and O C *, ſuppoſing A O parallel to the reflecting Plane, and O C perpendicular to it. Let A O be continued; the Motion in that Direction is not alter'd from the Action of the Plane: Therefore let A O and O B be equal; if the Light recedes from the Plane with the ſame Force, with which it came upon it, the Motion occaſion'd by the Repulſion is repreſented by C O, and in that Caſe

*190 the reflected Ray goes thro' B *; that is, the Angle O C B is equal to the Angle O C A, which agrees with the Experiment.

787 As to the Reflexion of Light, it is to be obſerv'd, that *Light does not run againſt the ſolid Part of Bodies, when it is reflected by them; but that it is reflected in thoſe Places, where it cou'd very freely paſs.*

paſs. I ſhall prove this by ſeveral Experiments, by which many other wonderful Properties of Reflexion are diſcover'd.

It is a common Experiment obſerv'd by every 788
Body, that when Light is mov'd thro' any Medium, as for Example, Glaſs, Water or Air, it does not undergo a ſenſible and regular Reflexion; but that it is reflected there, where two Mediums of different Denſity are ſeparated; ſo it is reflected in the Surface of Water or Glaſs.

Cou'd Light in ſuch Quantity ſtrike againſt the Particles, juſt where the Mediums are ſeparated, whereas it moves thro' both the Mediums for a great Space without ſtriking againſt any ſuch Particles; Are there more of thoſe Particles near the Surface than elſewhere? *Light* alſo *is more* 789 *abundantly reflected in a denſer Medium, when it comes againſt the Surface of a rarer; than when on the contrary, moving in a rarer Medium, it ſtrikes againſt the Surface of a denſer.*

Experiment 2. *Plate* XII. *Fig.* 3.] In a dark Place in which the Light enters thro' an Hole in the Plane L, let there be placed a triangular Priſm of Glaſs A B; let the Light enter the Priſm thro' one Side; if it comes to the next Side making an Angle of Incidence greater than 40 Degrees, it is wholly reflected, and does not at all penetrate into the Air; but Light moving in Air is never wholly reflected by the Glaſs.

But if the Reflexion be made by the ſtriking of Light againſt the ſolid Parts of Bodies, there muſt be more ſuch Parts in Air than in Glaſs; for if Light was reflected from the Glaſs itſelf into the Air, the Light would never come to the Separation of the Mediums; that the Light can alſo go out of Glaſs in the very Places, where it is reflected, is prov'd by following Ex-

periments. Therefore in the Neighbourhood of the Glaſs there muſt be ſo many Parts in the Air, that there may be no Way for the Paſſage of the Light, to cauſe it to be wholly reflected into the Glaſs; but it is plain that there are no ſuch Parts, becauſe Light comes thro' the Air in all Directions quite to the Glaſs. Even in the ſame Place of the Surface which ſeparates the Glaſs and Air, the Light which comes from one Side is reflected, whilſt that which comes from the other Side is tranſmitted. Which clearly proves that the Light is reflected in the very Place where it can go thro'.

790 *Experiment* 3. *Plate* XII. *Fig.* 3.] Every Thing being as in the former Experiment, if the Obliquity of the Light be chang'd, Part of it will paſs thro' into the Air.

Who wou'd conceive that Light, which paſſes from Glaſs into Air, and does not run againſt the ſolid Parts, ſhou'd all of it (by a little increaſing the Obliquity) run againſt thoſe Parts; when in each Medium, as has been already ſaid, there are Pores and Paſſages in all Directions?

791 *Experiment* 4. *Plate* XII. *Fig.* 3.] Take a Glaſs triangular Priſm A B, moveable about its Axis; which is made ſo by fixing braſs Plates to its Ends, with braſs Wires perpendicularly fix'd to them: The Priſm muſt be ſo laid upon the Trough P, as that the ſaid Wires may bear upon the Brims of it, which are made a little hollow to receive them, yet ſo as to let them turn, that the Priſm may move freely about its Axis: Let it be ſo plac'd as to reflect the Light in the ſame Manner, as in the ſecond Experiment. Let the Trough be fill'd with Water up to the Priſm; then the Light, which, ſtriking againſt the

the Air, was wholly reflected, now running againſt the Water, does partly enter into it, and is only reflected in part.

Which Experiment does not at all agree with a Reflexion made by a Stroke upon the ſolid Parts.

In the third Part of this Book we ſhall alſo ſhew, that thin Plates, which reflect Light, will tranſmit it, if they become thicker *. * 894

The fourth Experiment alſo proves that *the reflecting Power is ſo much greater, as the Mediums, which are ſeparated by a reflecting Surface, differ more in Denſity*; for Glaſs and Air differ more in Denſity than Glaſs and Water. 792

In this Experiment we alſo ſee that *Reflection is made by the ſame Power by which the Rays are refracted, which produces different Effects in different Circumſtances.* 793

A Ray, which goes out of a denſer into a rarer Medium, by the Attraction of the former, is made to recede from the Perpendicular *; if the Obliquity of the incident Ray be increas'd, the Obliquity of the refracted Ray will alſo increaſe, till it comes at laſt to move in the very Surface which parts the Mediums. And this obtains, when the Sine of the Angle of Incidence is to the whole Sine, as the Sine of Incidence, in the denſer Medium, is to the Sine of Refraction in the rarer; for in that Caſe the Angle of Refraction is a right one. If the Obliquity of the incident Ray be more increas'd, it is plain that the Ray cannot penetrate into the rarer Medium: This is the Caſe in which the Light is wholly reflected; which Reflexion depends upon that Attraction by which the Rays are refracted. For when the Ray is mov'd thro' the Space of Attraction, it is bent towards the denſer Medium *; if it be in the denſer Medi- * 625 * 618

um, and ſo bent, that, before it has gone thro' the whole Space of Attraction, the Tangent to the Curve be parallel to the Surface that ſeparates the Mediums, the Curve, being continued, turns back again; and therefore the Ray is reflected by the Attraction of the denſer Medium, and this Continuation of the Curve is ſimilar and equal to the firſt Part, and makes the Angle of Reflexion equal to the Angle of Incidence; becauſe the Light returns thro' the ſame Part of the Sphere of Attraction; and the ſame attracting Force acts upon the Light in correſpondent Points of the two Parts of the Curve. Thus a Projectile, in its Aſcent and Deſcent, deſcribes ſimilar Curves.

Yet that *all Reflexion does not depend upon that*
794 *Attraction, in the ſame Manner*, is evident; for in that Caſe, in which the Refraction is made, Part of the Light is reflected; for the Light does not wholly penetrate out of the rarer into a denſer Medium; for even in that Caſe, in which the Attraction is the moſt oppos'd to the Reflexion that is poſſible, yet ſome Rays are reflected.

Yet it cannot be doubted but that, *in every*
795 *Caſe, Reflexion has Relation to the refracting Power.*
796 *Where Light paſſes without Refraction, there it is*
* 617, 788. *not reflected**; *but where the Refraction is greateſt,*
* 631, 792. *there the Reflexion is alſo ſtrongeſt**; which is true, not only when Light, moving in a denſer Medium, ſtrikes againſt a rarer, as in the fourth Experiment; but the ſame Thing is obſerv'd, when Light ſtrikes againſt the denſer Medium: Thus ſuppoſing the Light to move in Air, the Surface of Glaſs reflects more ſtrongly than that of Water; and that of a Diamond yet more ſtrongly. If Glaſs and a Diamond be immers'd in Water; the refracting Power is leſs in the Separation of thoſe Bodies with Water, than where thoſe

thoſe Bodies touch the Air*. Theſe Bodies alſo * 631
reflect Light leſs ſtrongly in Water than in Air. From this Relation of the reflecting and refracting Powers, we deduce, that *Light is driven* 797
back at a certain Diſtance from the Bodies, in the ſame Manner that the refracting Power does alſo act at ſome Diſtance from the Body: This Propoſition is confirm'd from what has been demonſtrated concerning Reflexion, which does not depend upon a Stroke made againſt the ſolid Parts of Bodies; and this is fully made out, if we conſider, *that poliſh'd Bodies reflect the Light* 798
regularly (which we obſerve in Looking-Glaſſes) *tho there be a great many Scratches in their Surfaces:* For as they are poliſh'd with the Powder of *Emery* and *Putty*, tho their Parts are very ſmall, yet they leave very great Scratches on the Surface in Reſpect of the Particles of Light; whence in the Surface itſelf the Reflexion muſt needs be irregular; but if we conceive the Reflexion to be made at ſome Diſtance from the Surface, the Irregularities are diminiſh'd, and almoſt wholly taken off, as is eaſily underſtood by any one that conſiders it with Attention.

CHAP. XIV.

Of Plane Mirrors.

Plate XII. *Fig.* 4.] LET *b c* be the Surface of a Plane Mirror or 799
Looking-Glaſs; A a radiant Point. *Let the Plane of the Glaſs be continued, and from the Radiant* A *let a Perpendicular* A C *fall upon it; if this Line be continued, and* C *a be made equal to* C A, *a will be the imaginary Focus of the reflected Rays that proceed from* A. Let A *b* be the incident Ray; *b f* the reflected Ray; which continue beyond the Glaſs;

the Angles of Incidence and Reflexion are equal
784 to one another, their Complements alſo, which are the Angles A *b* C, *f b d* are equal; to this is equal its oppoſite and vertical *a b* C: The Triangles A *b* C, *a b* C, which are rectangular, have the Side C *b* common, and the Angles C *b a*, C *b* A, equal; therefore they agree in all Reſpects, and C A and C *a* are equal to one another: Which Demonſtration may be applied to all other Rays which flow from A, in whatever Plane, perpendicular to the Glaſs, they be conceiv'd to be. Therefore wherever the Eye is, if the reflected Rays come to it, they will enter the Eye as if they came from *a*; and the Point A will appear in that Place*; but *the Appearance of that Point*
*737 *will have the ſame Poſition in Reſpect of the Mirror,*
800 *behind it, as a radiant Point has before it.*

If this be applied to all the Points of the Ob-
801 ject, it will appear, that *the Object will appear behind the Glaſs in the ſame Poſition that it has before the Glaſs.*

CHAP. XV.

Of Spherical Mirrors.

802 EVERY ſpherical Surface may be conſider'd, as made of innumerable ſmall Planes; and a Plane, which touches the Sphere in any Point, is as it were a Continuation of ſuch a ſmall Plane.

803 Spherical Mirrors are either *Concave* or *Convex.*

The firſt are made of Part of an hollow Sphere poliſh'd.

The ſecond are Parts of Spheres poliſh'd on the Outſide.

A Ray coming upon any ſpherical Mirror, together with its reflected Ray, is in a Plane, which, being continued, goes thro' the Center of the Sphere *, for ſuch a Plane is perpendicular to the Surface of the Sphere. 804 * 782

A Line which is drawn thro' the Center of the Sphere and Point of Incidence, being continued makes equal Angles with the incident and reflected Rays *; for that Line is perpendicular to the Surface, and thoſe Angles are Angles of Incidence and Reflexion: Therefore *the Ray that goes thro' the Center, or which, being continued, wou'd go thro' the Center, when reflected returns upon itſelf.* 804 * 784 806

Plate XII. *Fig.* 5.] Let *b c* be a Portion of the convex Mirror; A a radiant Point; let A *b*, A *d*, A *c*, be incident Rays; the reflected Rays will be *b f*, *d g*, *c h*; *if from the radiant Point* A, *a Tangent be drawn to the Mirror*, the reflected Ray will be a Continuation of the incident, or rather *the Reflexion of the Rays terminated in the Point of Contact.* 807

If b f, *d g*, *c h*, *the Rays that are reflected from the convex Mirror, be continued*, with all the intermediate ones, by their Interſections they will form the Curve *a a*, which all theſe Rays touch, and the neighbouring Rays interſect in the Periphery of the Curve; ſo that they always enter the Eye as if they came from a Point of the Periphery; *in which* therefore *the Point* A *does* always *appear* *, as long as the reflected Rays can come to the Eye, and the Eye is mov'd in a Plane which goes thro' the Center of the Sphere; but when the Eye is mov'd out of that Plane the radiant appears in another Curve, becauſe there are ſuch Curves in every Plane, which may be conceiv'd to paſs thro' A and C. 808 * 737

Since all theſe Curves, and each of them wholly are behind the Glaſs, *all the Objects* alſo *appear behind the Surface of the Glaſs.* 809

810 *The Objects* likewiſe *appear erect.* For if the Point A be mov'd about the Mirror, the whole Curve *a a* is carried with the ſame Motion; which proves (in Reſpect to the erect inverſe Situation) that the Points of the Repreſentation have the ſame Relation to each other, as the Points of the Object itſelf.

As the Point A is farther remov'd from the Glaſs, the whole Curve does alſo recede by a contrary Motion; but ſuppoſing A at an infinite Diſtance, that Point of the Curve, which is the fartheſt remov'd from the Surface, will be diſtant from a Quarter of the Diameter; whence it
811 follows, that *the Objects appear diminiſh'd*, becauſe all the Repreſentations are compris'd in ſmall Limits.

812 *If the Eye be mov'd, the Appearance of the Object is alſo mov'd, and its Figure chang'd:* For all the Points are mov'd in their own Curves, and that unequally, according to the different Situation of the Eye in Reſpect of each Curve; whence of Neceſſity the Figure muſt be chang'd.

Experiment 1. *Plate* XII. *Fig.* 6.] If any one ſees his Face in a ſpherical convex Mirror, ſtanding at A, he will ſee his Face at *a* erect, diminiſh'd and unlike; by the Motion of the Eye one may obſerve the other Things mention'd in Reſpect to fix'd Objects.

813 *Let b d* (*Plate* XIII. *Fig.* 1.] be *a concave Mirror*, and a Portion of a Sphere whoſe Center is C; *let parallel Rays fall upon the Surface of the Mirror*, one of which, C *d*, is ſuppos'd to paſs thro' the Center; this Ray by Reflexion returns upon
* 806 itſelf *, and the Rays next to it, being reflected, become converging, and concur with it in the Focus F, which is the middle Point between *d* and C. Let A *b* be a Ray very little diſtant from C *d*; draw

front. page 90.

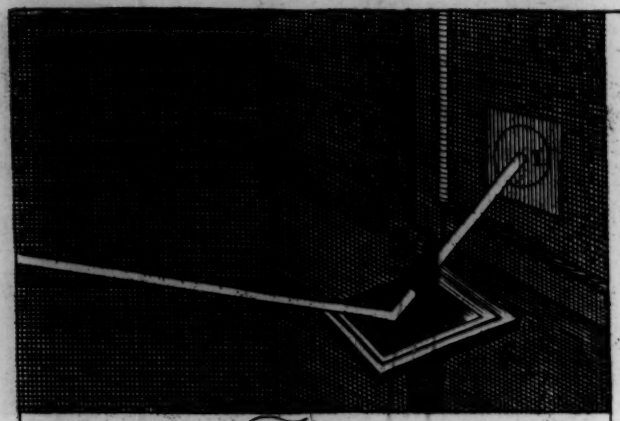


Fig. 1.

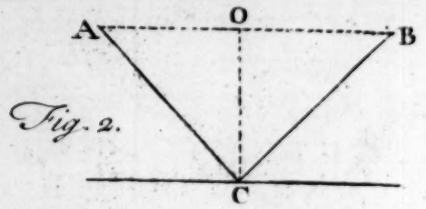


Fig. 2.

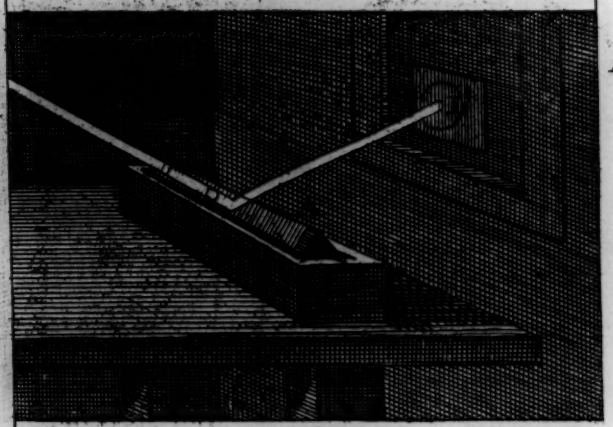


Fig. 3.

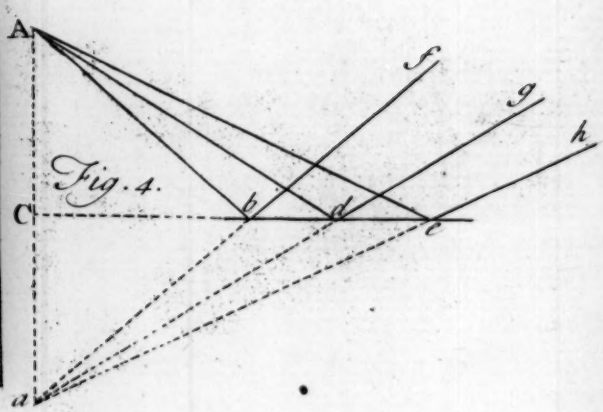


Fig. 4.



Fig. 6.

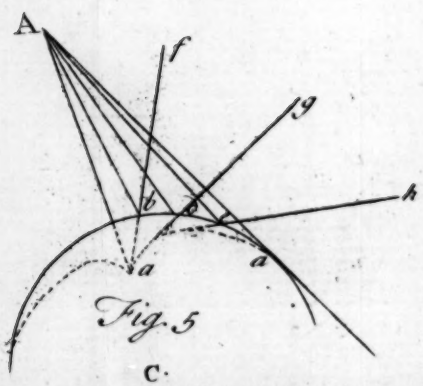
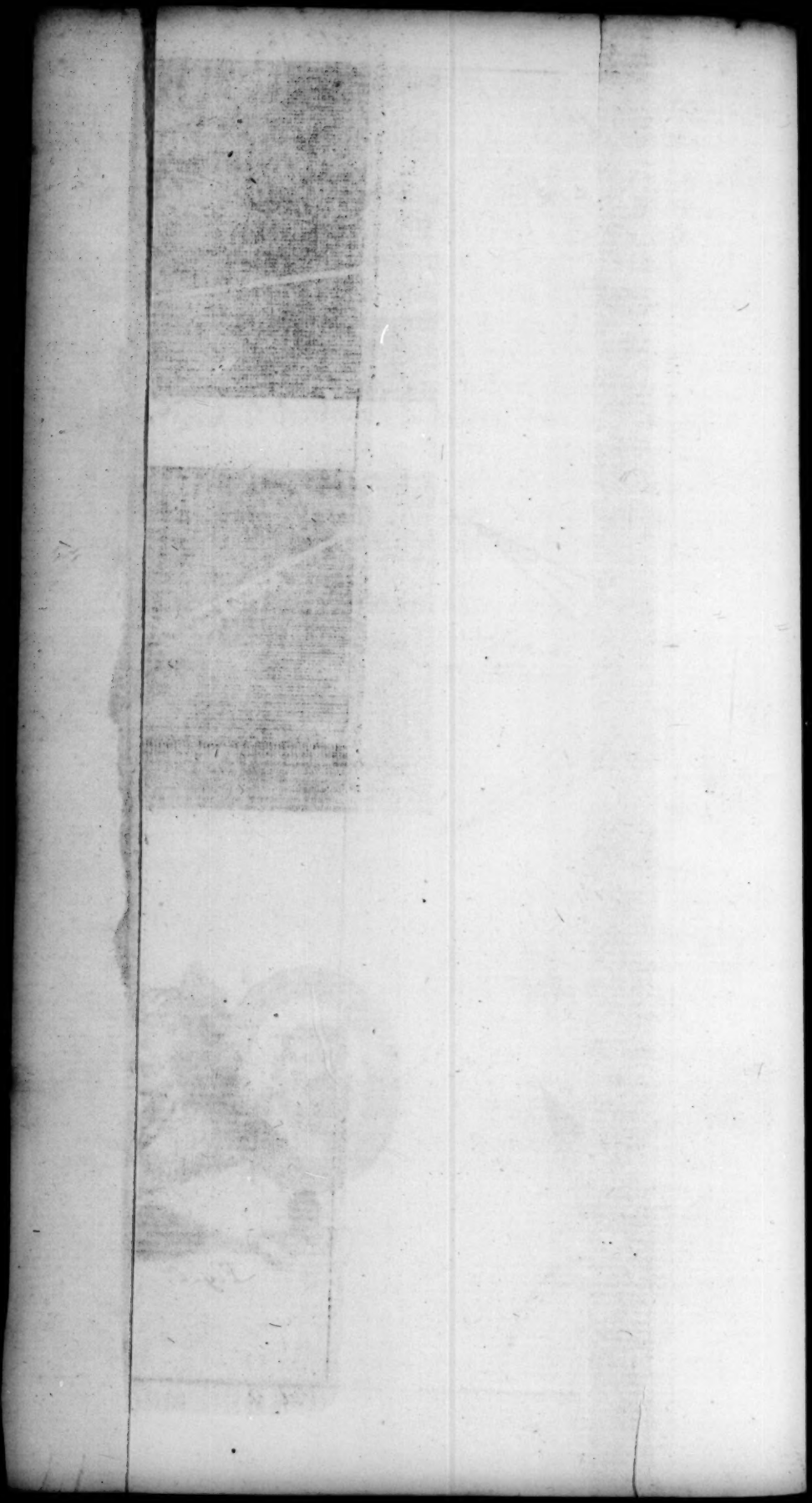


Fig. 5



the Semidiameter C *b*; the Angle of Incidence will be A *b* C, to which the Angle of Reflexion C *b* F * is equal, as alſo the alternate Angle * 805
b C F; therefore *b* F C is an Iſoſceles Triangle, and the Sides F C and F *b* are equal; becauſe *b d* is very ſmall, F *d* and F *b* do not ſenſibly differ; therefore F C and F *d* are equal; which Demonſtration will ſerve for all the Rays that are but very little diſtant from C *d*.

If parallel Rays are farther diſtant from C *d*, they do not meet at F; yet they will all come together into a little Circle, if the Diameter of the Mirror does not exceed the fifth or ſixth Part of the Diameter of the Sphere of which it is a Portion.

Burning Mirrors are made upon this Founda- 814
tion, which collect the Sun's parallel Rays into a Focus.

Experiment 2. *Plate* XIII. *Fig.* 2.] Let there be a concave Mirror S, made of Metal, or of Glaſs quickſilver'd behind; let it ſtand upon the wooden Foot P, whoſe upper Part is bor'd ſo as to receive a Cylinder of Wood made faſt to a tranſverſe Piece A A, which ſerves for turning the Glaſs round with a horizontal Motion; and the Mirror itſelf muſt move upon two Ends of an Axis between the Pillars A B, A B, ſo as to be inclin'd in any Angle, and the Screws B, B, will make it faſt in any Poſition.

Having expos'd the Burning-Glaſs to the Sun-Beams in ſuch a Manner, that the Ray, which comes upon the Middle of the Glaſs, is perpendicular to its Surface; ſince all the others are parallel to it, they are collected in a Focus, at a Quarter of a Diameter's Diſtance from the Glaſs, and there burn violently.

If

If the Diameter of the Surface of the Mirror (as it is in mine) be of about 15 Inches, and the Focus is 18 Inches diſtant from it, Wood will immediately be in a Flame, and thin Plates of Lead preſently melt.

If we conſider the Rays that are at ſome Diſtance from C *d*, and parallel to it, thoſe of them that are neareſt one another being reflected, will interſect before they come to C *d*, and
815 in that Caſe, that is, *where parallel incident Rays fall obliquely on the Glaſs, being a little diſpers'd by Reflexion, they are collected in a Point.*

816 *If the Focus, in which parallel Rays are collected by a concave Mirror, becomes the radiant Point*, the Rays, which are but little diſperſed, are refle-
* 813 cted parallel to one another*.

785 From theſe Properties of a concave Mirror
817 we deduce the Method of repreſenting Objects in a dark Place, much like what was before ſhewn in Reſpect of a Convex Lens*.

* 711 *Plate* XIII. *Fig.* 3.] Let there be an Hole F thro' the Wall; let a b be a concave Mirror, ſo plac'd as to collect the parallel Rays that are perpendicular to the Wall at F: The Rays, com-
* 816 ing from F in that Direction, are reflected *, and ſuch are the Rays, which, being reflected from the external Objects, interſect one another at F.

Let A F be Rays coming from a Point of a diſtant Object; theſe Rays are by the Mirror reflected perpendicularly to the Wall; and becauſe Rays coming from a diſtant Point, and paſſing thro' a ſmall Hole, may be looked upon as parallel, theſe Rays will, after Reflexion, be collected into one Point at *a*, at the Diſtance of
* 815 the Wall*, that is in its Surface; where therefore the Point will be repreſented. In the ſame Manner the Rays which come from a Point thro'

thro' B F, are collected at *b*; which, as it is true with Regard to all the Points of an Object, will give the Repreſentation of it upon the Wall; and if the Wall be white, and the Object enlighten'd by the Rays of the Sun, the Picture will appear in very lively Colours.

Experiment 3. *Plate* XIII. *Fig.* 4.] In a dark Place cover the Backſide of the Window-ſhut with white Paper, an Hole being made in the Middle of it little more than half an Inch Diameter, ſo as to anſwer to an Hole behind it in the Window-ſhut, over-againſt which, at a Diſtance no leſs than of 50 Foot, there are ſeveral Objects enlighten'd by the Sun: Let a concave Mirror whoſe Surface is 15 Inches wide, and which collects parallel Rays at the Diſtance of 18 Inches, be placed at that Diſtance from the Window, in ſuch Manner, that a Line paſſing thro' the Center of the Hole, and the Center of the Surface of the Mirror, be perpendicular to the Plane of the Paper and the Surface of the Glaſs. Then the Objects will be repreſented upon the Paper in a Circle concentric with the Hole, and whoſe Diameter is equal to the Diameter of the Mirror. You muſt join to the Hole, on the Outſide of the Room, an hollow, truncated Cone, to exclude the Light which does not come from the Objects to be repreſented.

Let *b e* (*Plate* XIII. *Fig.* 5.) *be a concave Mirror*; C the Center of its Concavity; A *a radiant Point farther diſtant than* C *the Center of the Glaſs*; A *b*, A *d*, A *e* incident *Rays*, whoſe *reflected* ones *b f*, *d g*, *e h*, with their intermediate ones *by their mutual Interſections form the Curve a a*, *which they touch*; therefore *the Point* A *appears in that Curve* *; and if the Eye be mov'd in the Plane of the Curve, the Appearance will change 818 * 803

Place

Place in that Curve. But in all the Planes which may be conceived to paſs thro' C A, there is ſuch a Curve, and they all concur in the Line
819 C A, namely, at the Point *a*. *Therefore in that Point a, the reflected Rays are the moſt abundantly collected*, which therefore is call'd the Focus of the Rays coming from A. On the contrary, A
* 785 will be the Focus, ſuppoſing the Radiant at *a**.

In this Figure there is only Part of the Curve drawn, which is produced by one Part of the Line A C; ſuch another Part muſt be conceiv'd on the other Side, and both join in the Focus of the radiant Point.

820 *As the radiant Point recedes, the Curve comes nearer the Mirror.*

821 As the Radiant comes forward, the Curve recedes from the Mirror, and moves towards the Radiant, till they concur *at the Center* C; in which, *if the Radiant be plac'd, all the reflected*
* 806 *Rays will coincide with the incident* *, and the whole Curve will, as it were, be ſwallow'd up in the Center.

822 *If the Radiant* is yet brought nearer to the Mirror, ſo as to *be between the Center and the Glaſs, the Curve will* recede farther, and *be* then *beyond the Center*; and in the Curve, that Point will recede moſt of all, in which all the Curves concur which are conceiv'd in ſeveral Planes, that is, the Focus of the radiant Point: And that Focus
823 will be at an infinite Diſtance *when the Radiant is diſtant from the Mirror juſt the fourth Part of the*
* 813 *Diameter of the Sphere.** Then alſo *the Curve is*
816 *extended in infinitum, and the two Parts* which concur in the Focus of the Radiant *are ſeparated*; this ſeparated Part is ſeen at a a: (*Plate* XIII. *Fig.* 6.) *If the Radiant be brought ſtill nearer, the*
824 *Curve Parts decline from one another*, becauſe the Rays, ſuch as A *b*, and thoſe nearer it, being reflected,

flected, do not touch the Curve, but become divergent; that is, thoſe reflected Rays, being continued beyond the Glaſs, will interſect one another, *and form a new Curve behind the Glaſs, which has two Legs*, one of which is ſeen at *a a*; they concur in the Line C A continued, namely, at *a*, and, receding from the Glaſs, are ſtretched out *in infinitum*. And there is alſo, on each Side of the radiant Point, a Point in the Surface as *d*, which ſeparates the Rays that form the Curves *a a* and a a; and the Ray A *d*, being reflected in *d g*, touches neither of the Curves, if it be infinitely continued toward each Part *g*, *g*, tho it is continually coming nearer to each Curve. If the whole Sphere was compleated, in Reſpect of the oppoſite Part of the Sphere, the Radiant would be beyond the Center, and the reflected Rays would form the Curve which we have mention'd before, * by which the ſeparated Legs, as a a, would be join'd. Theſe Things thus premiſed, we proceed to explain the Phænomena of concave Mirrors. * 818

If the Mirror be enlightened by a lucid Body, the Rays which come from all the Points of the Object, being reflected, will form Curves, but *are chiefly collected in the Foci of theſe Points*; * therefore *if theſe Foci are in the Surface of a white Plane, there will be upon it a Repreſentation of the lucid Body*, as in the ſecond *Experiment* of *Chap.* IX. And that Repreſentation will be *inverted*; for the Line, which joins the radiant Point with its Focus, goes thro' the Center of the Sphere; * in which therefore all ſuch Lines interſect one another; and this Interſection is between the radiant Point and the Focus, * in which the Point is repreſented. 825 * 819 826 * 819 * 818

But as the lucid Body is brought nearer to the Mirror, the Appearance recedes farther, * *and* in this Caſe *becomes bigger*. * 820

Experi-

Experiment 4.] Hold a lighted Candle between the Mirror and the Center of the Sphere of which it is a Portion; yet ſo that it may be more diſtant from the Mirror than that Center: If then there be a white Plane perpendicular to the Line that paſſes thro' the Candle and the Center of the Mirror, and this Plane be held beyond the Center, you will have upon it an inverted Repreſentation of the Candle; the proper Place will be found by moving the Plane forwards and backwards; as likewiſe by this Proportion, *viz.* As the Difference of the Diſtances of the Candle, from the Center of the Sphere and from the Mirror, is to the fourth Part of the Diameter of the Sphere, ſo is the Diſtance of the Candle from the Glaſs, to the Diſtance requir'd. As the Candle is brought nearer to the Speculum, the Plane muſt be mov'd farther off, and the Repreſentation will grow bigger.

827 *Plate* XIII. *Fig.* 5.] *Objects, placed beyond the Center, appear between the Glaſs and the Center,* for
* 818 all the Points appear in a Curve as at *a a*; * *the*
828 *Images of the objects will alſo be diminiſh'd and inverted:* for they are reduced into a narrow Space; and as the Point A moves downwards, its Repreſentation will be carried upwards; for the Line *a a* keeps the ſame Situation in reſpect of A C *a*, as it is carried round the Center C.

Experiment 5. *Plate* XIII. *Fig.* 7.] Leſt the Repreſentation of the Object ſhou'd be leſs vivid, the Mirror is to be included in a Box. If you have a Mirror, whoſe Surface is about 8 Inches wide, and which is a Portion of a Sphere of one Foot and a half in Diameter; ſhut it up in a Box P, in whoſe Fore-Part there is an Hole

of

of about 6 Inches Diameter, and from which the Glaſs is diſtant above 6 or 7 Inches; and let this Opening be turn'd from the Light. Now if any Perſon, as A, beholds himſelf at the Diſtance of about 2 Foot from the Glaſs; his Face will appear inverted in the Box towards the Hole; and if the Beholder comes nearer, he will ſee a Head coming out of the Hole.

The Repreſentation of a Point, placed in the Center of a Sphere, coincides with the radiant Point itſelf, and is as it were ſwallowed up by it *. 829 * 821

If the Eye be plac'd in that Center, no Object can be ſeen by it; for then only the Rays, that flow from the Eye, will be reflected to it *. 830 * 806

If the Object be between the Center and the Point, in which parallel Rays are collected after Reflexion, the Object will alſo appear without the Glaſs, at a greater Diſtance from the Glaſs than the Object itſelf *; *the Repreſentation is inverted*, which is proved in the ſame Manner as in N°. 828; *and magnified*, becauſe it is farther remov'd from the Center, than the Object itſelf is diſtant from it; for the Repreſentation recedes from the Center *in infinitum*; whilſt the Object goes thro' the fourth Part of the Diameter of the Sphere. 831 * 822

If the Object be leſs diſtant from the Mirror than the fourth Part of the Diameter of the Sphere, according to the different Situation of the Eye, the Object appears either before or behind the Glaſs. 832

Plate XIII. *Fig.* 6.] If the Eye be ſo plac'd, that thoſe Rays may come to it which form the Curve *a a*, as towards *f*, it will ſee the Appearance of the Objects towards the Glaſs * magnified; becauſe the Curves, as *a a*, which belong to ſeveral Points, are diverging. * 824

If thoſe Rays come to the Eye which form the Curve *a a*, the Object will appear without the Glaſs: And *in both Caſes the Repreſentation is* 833

erect; for as the Point A aſcends or deſcends, the Curves *a a* and a a, in which it is repreſented, are agitated with the ſame Motion.

834 *If the Eye be* in the Point, in which the reflected Rays, that belong to each Curve, interſect one another, *as in* O, *the Appearance of the Object will be double.*

It is plain in every Caſe of the Appearance, that the Points have not the ſame Relation to one another, as the Points of the Object; and

835 therefore that a *Concave Mirror never repreſents the Objects exactly:* But the moſt irregular Repreſentation of all is that which is in ſuch Lines, as a a.

836 There are alſo cylindric Mirrors convex and concave; theſe in one Reſpect are plane, and in another Reſpect ſpherical; and therefore the Repreſentation of the Objects is very irregular; which Irregularity, ſince it depends upon a regular Figure, may be ſo determin'd, that Pictures may be drawn, which, tho truly irregular, will in ſuch a Glaſs appear regular by Reflection, in a determinate Situation of the Eye.

CHAP. XVI.

Of the Magic Lantern.

THERE are ſeveral Machines made by the Combination of Mirrors and Lenſes, which afford uſeful and pleaſant Appearances; whoſe Explanation may be eaſily deduc'd from what has been ſaid.

Among many other I ſhall only chuſe to explain one, in which Figures, that are painted upon ſmall Pieces of Glaſs, are repreſented monſtrouſly large upon a white Plane. This is a Phæno-

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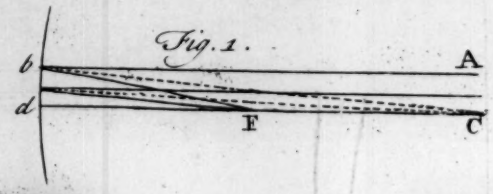
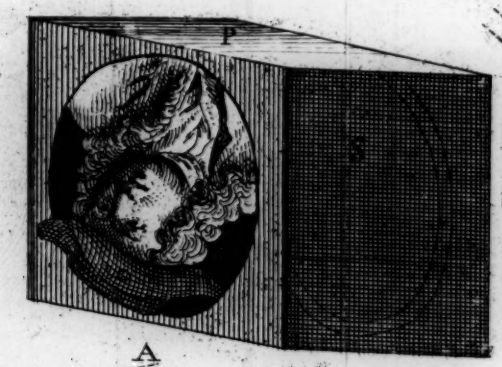


Fig. 1.



Fig. 7.



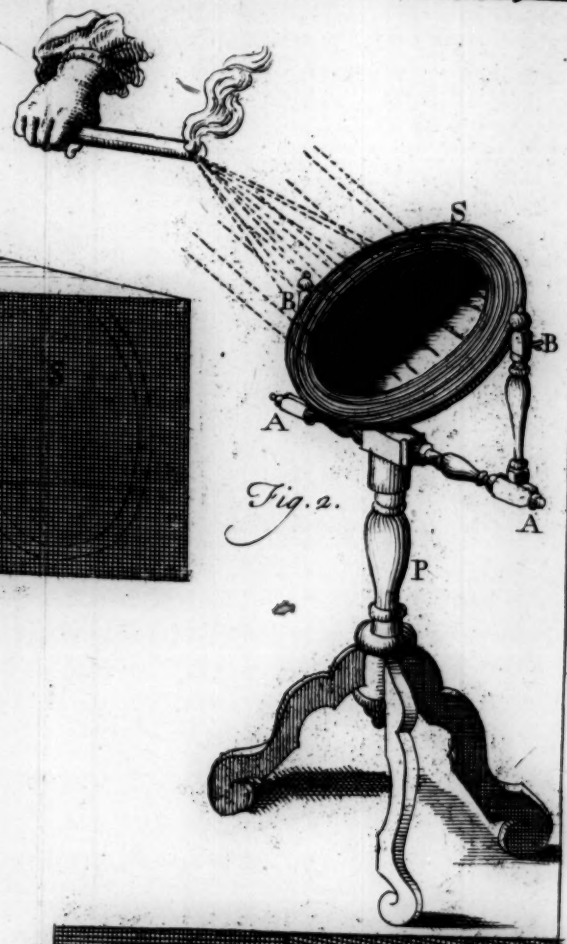


Fig. 2.

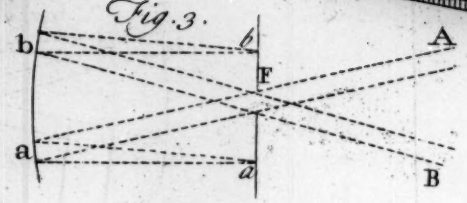


Fig. 3.

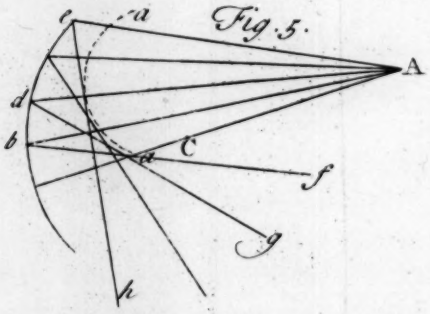


Fig. 5.

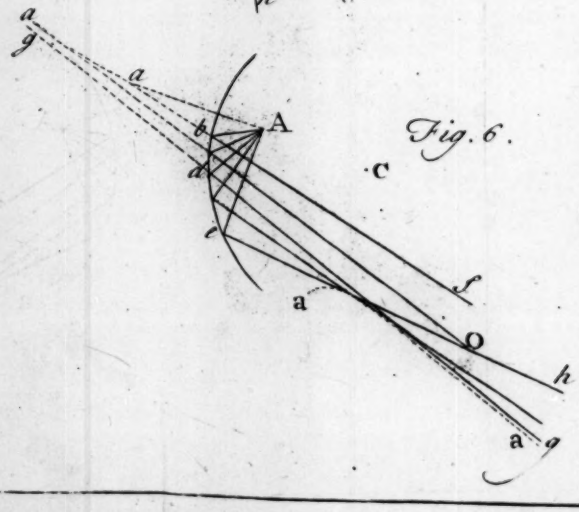


Fig. 6.



Fig. 4.

Phænomenon wonderful enough to deſerve a particular Explanation. The Inſtrument that performs this is call'd a *Magic Lantern*, which Optic Writers have not altogether paſs'd by, but yet have not ſufficiently explain'd.

Plate XIV. *Fig.* 1.] Let there be a wooden 837
Box about a Foot and an half long, 14 Inches high, and as wide; there muſt be a concave Mirror S, of 8 Inches Diameter, and a Portion of a Sphere of 18 Inches: This Mirror is fix'd to a Foot which moves upon Rulers, along the Length of the Box.

There is alſo in this Box a Lamp L, ſuſtain'd by a wooden Foot which is moveable long-wiſe between two Rulers, in the Side of the Box. The Pipe of the Lamp ſtands forward in ſuch Manner, that the Center of the Flame is over-againſt the Center of the Surface of the Mirror; this Flame is made up of four little Flames, which, by touching one another, make one ſquare Flame, two Inches wide.

In the Top, or upper Plane of the Box, there is an oblong Hole, which has a Cover that ſlides to two Grooves, or between two Rulers or Ledges: Thro' this Cover paſſes the Chimney C, which (as you ſee in the third Figure) ſtands up about one half Foot above the Box. The Chimney is moveable with the Cover, whilſt the Opening remains ſhut; that the Chimney may be always over the Lamp.

In one of the little Sides of the Box, which is overagainſt the Mirror, there muſt be a round Hole about 5 Inches wide; which muſt have in it a Convex Lens of Glaſs of the ſame Bigneſs V, convex on both Sides, which are Portions of a Sphere of one Foot Diameter: The Axis of this Glaſs, being continued to the Surface of the Mirror, will be perpendicular to it, and fall

upon its Center, as likewiſe to the Plane of the Flame, thro' whoſe middle Point it alſo paſſes.

This Hole is ſhut and open'd by a Plane moveable in a Groove, which is mov'd by a Cylinder that ſtands out of the Box at E.

To this Hole without the Box anſwers the Tube T, whoſe Length and Diameter is of about 6 Inches, at the End of which there is a Ring, in which the ſecond Tube *t* moves, of about 4 Inches Diameter, and 5 or 6 Inches long.

In the leſſer Tube there are two Lenſes; the firſt in that End which is thruſt into the Tube T, and it is of the ſame Convexity as the Glaſs V, and three Inches and a half Diameter. The ſecond Lens is three Inches from the firſt, and flatter, being terminated by Portions of a Sphere of four Foot Diameter. Between theſe Lenſes, at the Diſtance of about one Inch from the ſecond, there is plac'd a wooden circular Stop, or Aperture, which ſhuts up all the Tube, except an Hole of an Inch and a Quarter Diameter in the Middle of the Wood.

The Objects, that are to be repreſented, are to be painted upon a flat thin Piece of Glaſs, which muſt be mov'd without the Box over-againſt the Glaſs V, between it and the Tube T, the Picture being in an inverted Poſition. If theſe Pictures are round, they may be of 5 Inches Diameter: That they may be moved eaſily, they are put into flat Boards, three in one Board. The Picture alſo may be painted upon long Glaſſes, which may be ſucceſſively made to ſlide before the Glaſs V.

Plate IV. *Fig.* 3.] This whole Box ſtands upon a Frame or Foot, made ſo that it may be fix'd at different Heights. There are flat Pieces of Wood fix'd to the Box, at Bottom, which ſlide in Grooves in the Frame; each of them has a Slit

Slit in it; ſo that the Box may be made faſt at any deſir'd Height, by the Help of Screws join'd to the Frame, and moveable in the Slits.

The whole Machine is placed at the Diſtance of 15, 20, or 30 Feet from a white Plane, which Diſtance muſt be different according to the Bigneſs of the Plane; for this Diſtance may be equal to the Length of the Plane: The Box muſt be juſt at ſuch an Height that the Tubes, in the Side of the Box, may be exactly oppoſite to the Middle of the Plane.

The Lamp being lighted, the Box muſt be ſhut, and the Figures which are painted upon the Glaſs will be repreſented upon a white Plane. By moving backwards and forwards the Tube that has the two Lenſes in it, you will find the proper Poſition of the Glaſſes requir'd to give a diſtinct Repreſentation. As for the Diſpoſition of the ſeveral Parts of the Machine, which immediately ſerve for exhibiting this Appearance, we ſhall here more particularly explain.

Plate XIV. *Fig.* 2.] The Parts in this *Figure* 838
are ſhewn ſeparately; S S is the Mirror, *l l* the Flame which conſiſts of four Flames in the Line *l l*; V V is the Glaſs V of the firſt Figure; O O is a Picture painted upon a flat thin Piece of Glaſs; *a a* the biggeſt Lens; *d d* the flatteſt Lens; *b b* the wooden Stop between the Lenſes; *f* the Aperture or Hole in the Middle of the wooden Circle.

Theſe Things being diſpos'd as has been already explain'd, and as may be ſeen in the Figure, the Rays which proceed from a Point of the Picture O O, by going thro' the Lens *a a*, become leſs diverging, and fall upon the Lens *d d*, as if they came from a Point more remote*; * 669
from this Lens they go out more converging*, * 699
and are collected upon the Surface of the white

Plane, where they exhibit the Point of the Pi-
*711 cture that is painted on the Glaſs *. This Picture is illuminated both by the Rays that proceed from the Flame *l l*, and by the Rays reflected by the Mirror S S.

839 For the Perfection of this Machine it is requir'd, 1*ſt*, That the Figure O O be enlighten'd as much as poſſible; 2*dly*, That it be equally enlighten'd in all its Points; 3*dly*, That all the Light, by which every Point of the Picture is enlighten'd, go thro' the Lenſes *a a* and *d d* to the white Plane, and ſerve to make the Repreſentation; 4*thly*, That no other Light but that go out of the Box, leſt the Repreſentation ſhou'd be leſs lively, by reaſon of extraneous Light.

The firſt Requiſite depends upon the Bigneſs of the Flame and of the Mirror, and of its Concavity; the more concave it is, the nearer it is to be brought to the Flame, and then the more Rays will be intercepted and reflected; yet Care muſt be taken that the Mirror (which may be made of very good Glaſs) be not too much heated.

When the Flame and Mirror are ſo contriv'd, that the Picture is the moſt enlighten'd that it can poſſibly be, and every where equally enlighten'd, the Flame and Mirror muſt be ſo plac'd, that the inverted Image of the Flame
*826 ſhall fall juſt upon the Picture *. Now, as the Repreſentation of the Flame can be increas'd
*826 and diminiſh'd *, the Mirror and Flame muſt be ſo diſpos'd, that the Repreſentation of the Flame ſhall cover the whole Picture upon the Glaſs, but ſo as not to exceed it: For then the Picture is as much enlighten'd by the reflected Light as it can be, and all its Points are equally illuminated; the direct Light alſo does pretty near

near equally fall upon all the Points of the Picture; this Light wou'd indeed be increas'd by bringing the Flame nearer; but the reflected Light wou'd be diminiſhed, and the Diminution of this laſt wou'd be greater than the Increaſe of the other.

The Glaſs V V ſerves to inflect the Light, by which the Picture O O is illuminated, before it comes to the Picture; by which Inflection all the Light comes to the Lens *a a*, and ſerves for the Repreſentation on the white Plane.

All the Light, that is of Uſe for this Repreſentation, goes thro' the Hole *f*; and the Rays, coming from different Points, interſect one another there; wherefore the Picture upon the Glaſs, which is placed inverted, is repreſented erect upon the white Plane; by the Ring *b b* all the Rays, which do not ſerve to form the Repreſentation, are intercepted, leſt they ſhou'd enter the Room, and make the Picture leſs diſtinct. This Ring or Aperture alſo intercepts thoſe Rays by which one Point is more enlighten'd than another, whereby the Light, which (from what has been ſaid) is equally enough diffus'd, is yet made more equal. But unleſs the Stop or Aperture *b b* be juſt where the Rays interſect, it does a great deal of Miſchief.

BOOK III.

PART III.

Of Opacity and Colours.

CHAP. XVII.

Of the Opacity of Bodies.

DEFINITION.

840 

BODIES that tranſmit the Light are call'd Tranſparent. Such are
615 all Mediums, except a *Vacuum*.
841 *There is no Body whoſe ſmalleſt Parts are not tranſparent:* No one who is uſed to Microſcopes will doubt of this. There are ſome Parts of Metals, which, tho very ſmall, do not tranſmit the Light: But if they be diſſolv'd in *Menſtruums*; that is, if they be divided into much leſs Parts, they become tranſparent. One may alſo prove by a very eaſy Experiment, that Light can go thro' ſeveral opaque Bodies.

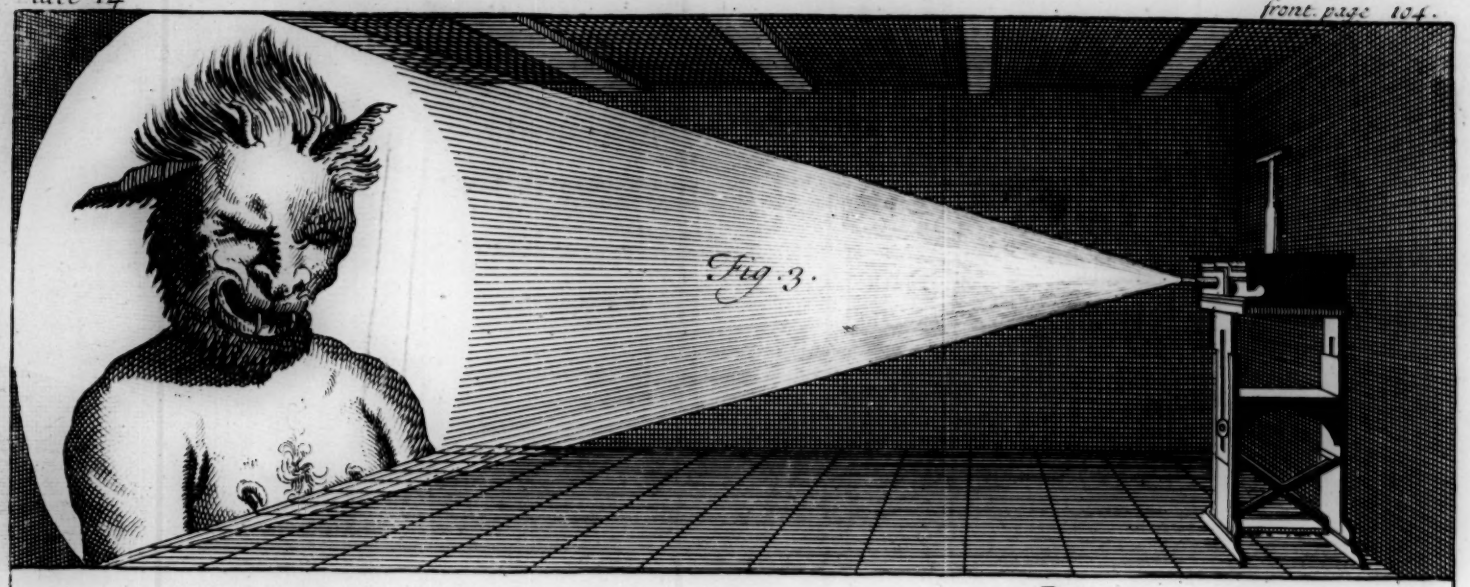


Fig. 3.



Fig. 2.



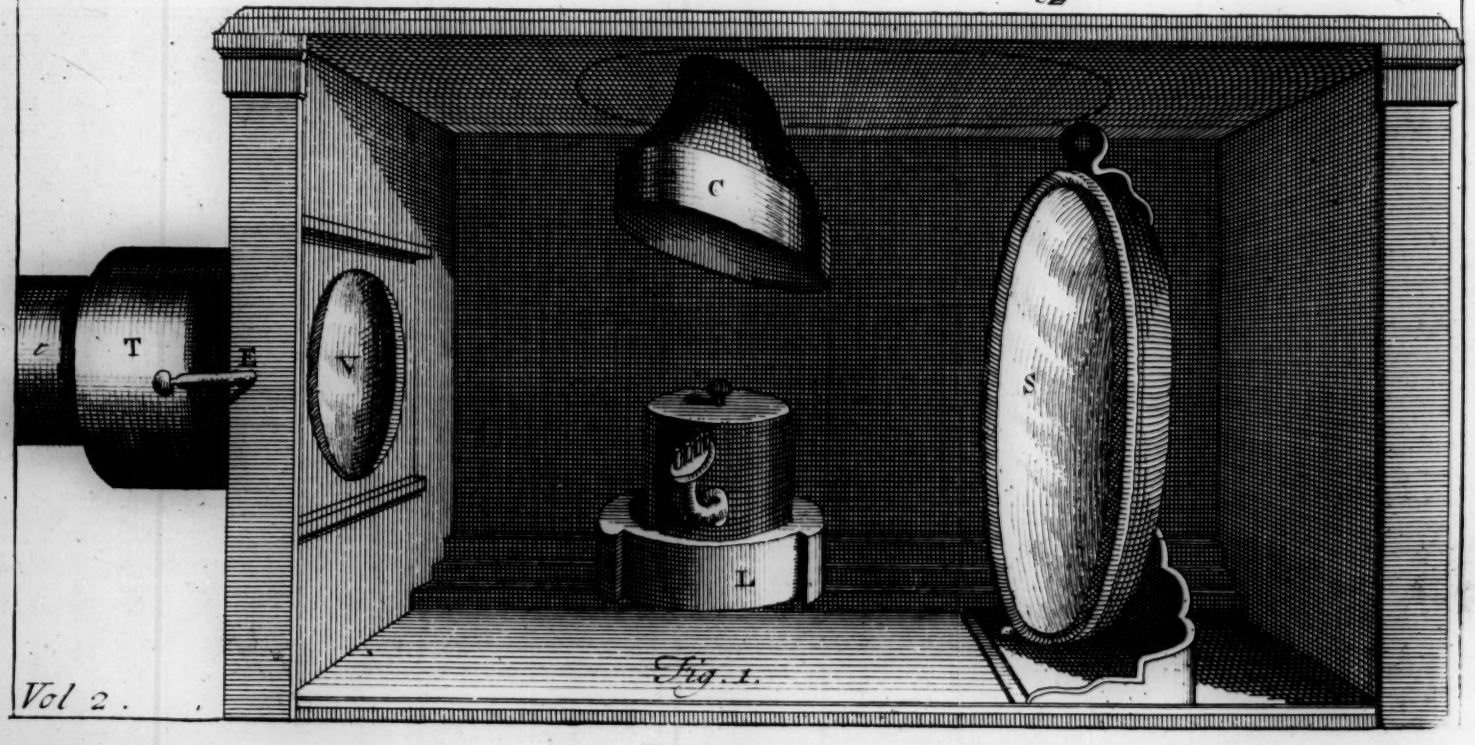
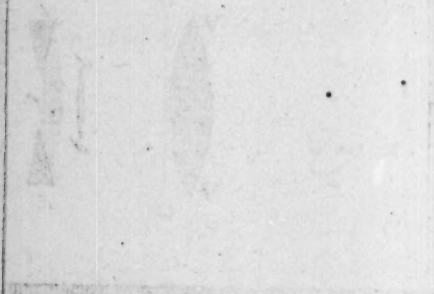
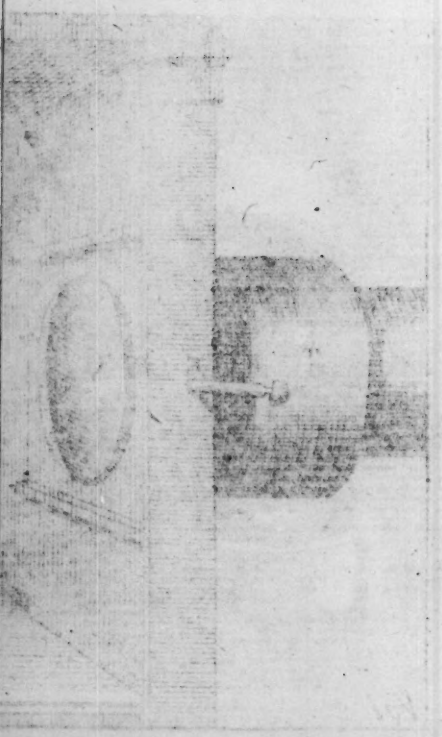


Fig. 1.

Vol 2.







Experiment 1.] In a dark Room, in which the Sun's Light comes in thro' an Hole, let that Hole be cover'd with a thin Plate of an opaque Body, and the Light will go thro' it; a Piece of Wood, of the Thickneſs of the tenth Part of an Inch, does not intercept all the Light. But the perfect Tranſparency of Parts in opaque Bodies is not prov'd by this Experiment, for that Tranſparency is only in very ſmall Parts.

Opacity does not (as is commonly imagin'd) *happen in Bodies, becauſe the Way, thro' which the Light might paſs, is ſtopp'd by Particles of Matter*; for Light paſſes thro' all the ſmalleſt Parts of Bodies; neither is ſuch an Interception of Light of any Uſe to cauſe Opacity: It is requir'd for Opacity that the Light ſhou'd be reflected and deflected from a right Line, for which there is only requir'd the Separation of two Mediums *. 842 * 631

Let us conceive a Body, conſiſting of very ſmall Parts, perfectly tranſparent (ſuch as are the Particles of which Bodies conſiſt *) and ſeparated from one another by Pores; and that thoſe Interſtices are either void, or fill'd with a Medium whoſe Denſity is different from that of the Particles; if Light enters ſuch a Body, it will every Moment fall upon a Surface dividing Mediums differing in Denſity; therefore it will undergo innumerable Reflections and Refractions in that Body *, ſo as not to be able to get thro' it. Therefore we ſee that *Opacity depends upon the Pores*; for *if you fill the Pores with a Medium of the ſame Denſity as the Particles of the Bodies themſelves*, the Light will undergo no Reflection or Refraction in the Body, but paſs directly thro' *, and *the Body will be tranſparent*. 796 * 841 * 631 796 843 * 841 631

Tho 697

Tho we cannot make Experiments, whereby to fill the Pores of the Body with a Medium exactly of the ſame Denſity as the Particles, yet the following Experiments will clearly enough prove Sir *Iſaac Newton*'s Doctrine concerning Opacity.

Experiment 2.] Paper becomes more tranſparent, when moiſten'd with Water; for it fills the Pores, and differs leſs in Denſity from the Particles than Air does. Oil has the ſame Effect.

Experiment 3.] Take a Piece of Glaſs two Inches thick; and take ſeveral Plates of the ſame Sort of Glaſs laid upon one another, yet ſo as not to be quite two Inches thick; and you will find that theſe will be leſs tranſparent than the ſolid Piece, becauſe of the Air between the Plates, which does not get into the ſolid Piece where all the Parts cohere.

Experiment 4.] Take twelve Plates of the ſame Glaſs, as near as may be of the ſame Thickneſs; let ſix and ſix of them be laid together; if you take the leaſt tranſparent of thoſe two Particles, and, having dipp'd it in Water, take it out again, it will become more tranſparent than the other; becauſe the Water, which in that Caſe fills the Interſtices between the Planes, differs leſs in Denſity from the Glaſs than Air does.

What has been ſaid of Opacity is farther confirm'd, and put out of all Doubt by innumerable
844 Experiments, by which *Bodies perfectly tranſparent become opaque, by the Separation of their Parts*, without the Intervention of any opaque Body.

Experi-

Experiment 5.] Let any perfectly tranſparent Liquid, that may be chang'd into Froth, be ſhak'd, till it be full of Bubbles; it will immediately become opaque, by reaſon of the Interſtices that are fill'd with Air.

Experiment 6.] Turpentine and Water are tranſparent Bodies, but, when mix'd, they become opaque.

Experiment 7.] Water and Oyl, by being mix'd together, become opaque, tho, ſingly, they are tranſparent.

Experiment 8.] Tho Glaſs be tranſparent, yet if it be reduced to Powder it becomes opaque; as it alſo does when it is crack'd.

We clearly ſee in all theſe Caſes that Opacity is produc'd, becauſe there is a Medium of different Denſity between the tranſparent Parts; which may alſo be obſerv'd in the Clouds, which are opaque on account of the Air interpos'd between the Particles of the Water.

If we add to this what is ſaid in the 22d Chapter following, concerning the Colours of thin Plates, we ſhall have new Experiments, by which alone it is fully prov'd that Bodies intercept the Light, becauſe they conſiſt of very thin Particles, encompaſs'd with a Medium differing from them in Denſity.

Some opaque Bodies reflect a little Light, and the reſt of the Light, by innumerable Diviſions which it undergoes in the Reflections and Refractions above-mention'd, is extinguiſh'd in the Body; ſuch are black *Bodies*; if there were any Bodies *perfectly black*, they *wou'd reflect no* 845
Light; for all Bodies, when no Light falls upon

them, and therefore they reflect no Rays, appear black.

Other opaque Bodies appear to have various Colours; ſome tranſparent Bodies are alſo ting'd with Colours: And whence thoſe ariſe we are now to examine.

CHAP. XVIII.

Concerning the different Refrangibility of the Sun's Rays.

BODIES appear differently colour'd, tho' they be enlighten'd by the ſame Rays of the Sun which are reflected by them. Beſides theſe there are ſeveral Phænomena of Light, relating to Colours, not to be overlook'd.

846 In theſe we are to obſerve three Things. 1*ſt*, The Rays are to be examin'd. 2*dly*, Their Reflection is to be obſerv'd. 3*dly*, We are to enquire into the Conſtitution of the Surfaces of Bodies differently colour'd.

847 As to the Rays, the firſt Property, to be taken Notice of here, is, that *in the ſame Circumſtance all Sorts of Rays do not undergo the ſame Refraction.*

DEFINITION I.

848 *The Rays, which undergo this different Refraction, are ſaid to have a* different Refrangibility, and *thoſe are ſaid to be* moſt refrangible, *which are moſt inflected by Refraction.*

DEFINITION II.

849 *Thoſe Rays are ſaid to be* Homogeneous, *which do not differ from one another in Refrangibility.*

DEFI-

DEFINITION III.

And thoſe are call'd Heterogeneous, *which, under the ſame Circumſtances, are not equally inflected by Refraction.* 850

Plate XV. *Fig.* 1.] Between A B and C D let there be a Sun Beam made up of an innumerable Quantity of parallel Rays; theſe are not equally refracted; for if they fall obliquely on the Surface B D of the denſer Medium, ſome of them are refracted between B E and D G, and are mov'd according to that Direction in the denſer Medium; others are more inflected, and direct their Motion between B F and D H according to the Direction of thoſe Lines; and indeed no Direction can be conceiv'd between the Mediums, along which the Rays do not move in every Point between B and D: So that the leaſt Beam whatever is, by Refraction, divided into an innumerable Quantity of Rays; becauſe every Sun-Beam, however ſmall, is heterogeneous, and conſiſts of an innumerable Quantity of Rays refrangible in all Degrees of Refrangibility.

The above-mention'd parallel Rays falling upon a plane Surface, by Refraction, are mov'd between B E and D H; which Lines diverge from each other, and, being continued, are more and more ſeparated; ſo that the Rays above-mention'd are diſpers'd by Refraction. In N°. 653. *We have conſider'd the Rays as homogeneal,* as alſo every where *in the Foregoing Part*; the Difference of Refrangibility is ſmall enough in the Rays of the Sun, not to have been worth obſerving in the foregoing Propoſitions. Beſides, we were firſt to examine what happens in homogeneal Rays; and what muſt be chang'd in the Propoſitions, upon account of the different Refrangibility, will eaſily appear. 851

That

582 That this Refrangibility of the Rays may be made viſible, the above-mention'd Divergence muſt be increas'd; which will be perform'd, if the Rays above-mention'd fall upon the Surface E H, which terminates a denſer Medium, and ſeparates it from the rarer Medium, and which makes any Angle with the Surface B D, and is ſo inclin'd to it, that the Rays, which are more refrangible, fall more obliquely upon it than thoſe that are leſs refrangible; ſo that the former, going into a rarer Medium, are more turn'd out of the Way, and diverge more from the others upon a double Account, that is, both upon the Account of a greater Refrangibility, and of a greater Inclination. The Rays between B E and D G, which are the leaſt refrangible, being refracted a ſecond Time, continue their Motion between E I and G L, the others between F M and H N: In which Caſe, if theſe Rays fall upon a Plane at the Diſtance of 15 or 20 Foot, thoſe that are moſt refrangible will be ſeparated from thoſe that are leaſt refrangible, and the whole intermediate Space is enlighten'd with Rays endow'd with a mean Refrangibility.

Experiment 1. *Plate* XV. *Fig.* 2.] Let there be an Hole in the Plate of a Metal in the Window-ſhut, of about a Quarter of an Inch, thro' which a Sun-Beam enters the darken'd Room: Let this Beam fall upon a triangular Priſm of Glaſs A A, in ſuch Manner, that it may be wholly reflected by the lower Surface (ſee the *Exper.* of N°. 789.) By the two Refractions which the Light undergoes, Rays that are differently refrangible do not diverge, and, being reflected, come upon a ſecond Priſm B B, which is likewiſe of Glaſs, and triangular, in the ſame Manner, as if they had come directly from the Sun.

Theſe

Theſe two Priſms are moveable about their Axes, as we before explain'd *; the firſt A A * 197
is laid upon a Piece of Wood faſten'd to it, yet ſo as not to hinder it from turning about its Axis; this Piece of Wood is faſten'd to a Three-legg'd Staff with a Ball and Socket, ſuch as is us'd in practical Geometry. The ſecond Priſm B B is laid on a Frame or Stand S, in whoſe oppoſite Sides there are ſeveral Slits that anſwer one another; by theſe the Priſm is ſuſtain'd at different Heights, but always horizontally, the End of the Axis being plac'd in correſpondent Slits.

The Light, that comes to the Priſm B B, moves perpendicular to its Axis, and paſſes thro', as is demonſtrated in *Fig.* 1. in which B D and E H repreſent the Sides of the Priſm; the Light is alſo equally inclin'd to each Side; which will happen by moving the Priſm about its Axis; for the Light of the Sun (as you move the Priſm) will aſcend, and then deſcend again; and the Situation requir'd is that in which the Light is higheſt of all: Now both the Priſms are to be ſo diſpos'd, that in this Caſe the Light may go horizontally out of the Priſm B B. This horizontal Beam, at the Diſtance of 15 or 20 Foot, muſt fall upon the Board T which is cover'd with white Paper, and has ſuch a Foot, that upon it, it may be rais'd and fix'd at different Heights. The Rays come diverging to the Paper, and upon it form the Oblong Image R V, terminated at the Sides by parallel Lines, but ſemicircular at R and V.

If the Rays of the Sun, that go thro' the round Hole, fall upon a Plane at a certain Diſtance, they will form a bright round Spot, ſo much the greater, as the Plane is more diſtant from the Hole; which ariſes from the Rays that come

come from the Sides of the Sun, which making an Angle with thoſe that come from its Center to the Hole, and interſecting them in the Hole, gives the Image of the Sun upon the Plane.

If the Rays did not go thro' the Priſm B B, and fall upon the Plane at the Diſtance of the Board T, the Image of the Sun wou'd have its Diameter equal to the Breadth of the Image V R; which Breadth is not alter'd by the Re-
853 fraction, becauſe the Rays enter the Priſm perpendicular to its Axis, and, in Reſpect of the Breadth of the Image, are not inclin'd to it. But as, in another Reſpect, the Image of the Sun is *oblong*, it follows plainly from thence, that all the Rays have not undergone the ſame Refraction; for homogeneous Rays, tho refracted, will give a round *Image of the Sun*. The leaſt refrangible Rays go to R, and the moſt refrangible to V; and the whole Image R V is terminated with Semicircles at R and V, becauſe the whole Image *conſiſts of Circular Images*. Now between R and V there are innumerable Quantities of circular Images, made by Rays of all poſſible Refrangibilities; otherwiſe the Image R V wou'd not be terminated with rectilinear Sides.

854 In moſt Experiments, we have ſaid that the Light is let into the darkened Room thro' a Slit or an Hole, which we leave to the Contrivance of the Workman; our Method was the following.

Plate XV. *Fig.* 3.] We made an Hole 4 Inches ſquare in the Window-ſhut, which on three Sides had Ledges of Wood A B, B C, C D, ſo rabbetted, as to make Grooves to keep in the ſquare flat Piece of Wood Q L, which is ſix Inches long, and ſix Inches wide. It may be drawn out, and

and ſeveral Sorts of them ſerve for ſeveral Experiments. That which we uſe in the following *Experiment* has a Hollow and a Hole in the Middle behind to contain a convex Lens, which is the Object Glaſs of a Teleſcope of 16 or 20 Foot; the round Hole in the Middle mark'd *f* is above half an Inch in Diameter, thro' which the Rays of the Sun, paſſing thro' the Glaſs, enter the Room. In the Fore-part alſo the Board Q is hollow'd, but not in the Middle; this Hollow contains the braſs round Plate L, which towards its Circumference has an Hole at *f*, which Hole is equal to the Hole in the Board Q itſelf, and agrees with it. Together with L there is another concentric Plate, which is leſs, and moveable about the Center; this Plate has ſeveral unequal Holes, which ſucceſſively come to *f* as the *Plate* is turn'd round; ſo that you may at Pleaſure let the Light enter a dark Place thro' a bigger or a leſſer Hole; which in many Experiments, that are made without the Lens above-mention'd, is of good Uſe. The *Pin m*, join'd with the Plate, ſerves to turn it by.

Experiment 2.] Let in a Sun-Beam thro' the Lens above-mention'd, thro' an Hole a Quarter of an Inch wide, into the darken'd Room; by the Rays thus let in, at the Diſtance where parallel Rays are collected, the Sun is very exactly repreſented, and its Image terminated with exactly deſcrib'd Bounds. For the Rays that come from the ſeveral Points of the Sun, which, by reaſon of its immenſe Diſtance, may be look'd upon as parallel, are collected in one Point at that Diſtance.

Plate XV. *Fig.* 2.] Now if with theſe Rays you make the Experiment above-mention'd, the

ſeveral Images made by the homogeneal Rays, ſuppoſing the Board at a juſt Diſtance, are exactly terminated; and therefore the oblong Image R V, which is made of all theſe Images, is likewiſe regularly terminated.

This Experiment will ſucceed in the ſame Manner, if the Rays paſs thro' a Priſm made of any Body which is denſer than Air.

Experiment 3. *Plate* XV. *Fig.* 2.] Let a triangular Priſm be made of Wood and two glaſs Planes, and fill'd with Water; ſuch as is repreſented at B B (*Plate* XVII. *Fig.* 3.) If you make uſe of this Machine inſtead of the Priſm B B in this *Fig.* the Experiment will ſucceed in the ſame Manner; and, in paſſing thro' Water, heterogeneous Rays in the ſame Manner are ſeparated by Refractions.

Experiment 4.] If any Perſon, ſtanding 15 or 20 Foot off, looks at the Hole thro' which the Light is let in, it will appear round; but if before his Eyes he hold a triangular glaſs Priſm, or the watery one mention'd in the laſt Experiment, ſo that the Rays coming from the Hole (after ſuch Refractions as the Light ſuffers in the foregoing Experiment) reach the Eyes, the Hole will appear oblong. The Situation of the Priſm will be found, if holding it horizontally with one Edge (or the refracting Angle) upwards, it be a little mov'd about its Axis, ſo as to make the Image of the Hole to aſcend and deſcend; and the Priſm be held faſt in that Poſition in which the Hole appears moſt depreſs'd.

This Experiment, as well as the foregoing ones, proves the different Refrangibility of the Rays; for by the homogeneal Rays of each Refraction, the Hole appears in the imaginary Foci of the Rays coming from the ſeveral Points

of

of the Hole *, which Image is round; the Rays, * 737
which undergo a different Refraction, enter the Eyes in different Directions; and you have ſeveral Images, all which form the oblong Image, which is really ſeen.

But that *this different Refrangibility does not depend upon the refracting Medium, but the different Conſtitution of the Rays themſelves*, is prov'd, becauſe thoſe Rays, which in one Caſe undergo the greateſt Refraction, are in any Refraction turn'd out of the Way more than any. 855

Experiment 5. *Plate* XV. *Fig.* 4.] All Things being diſpos'd, as in the firſt Experiment, at any Diſtance from the Priſm B B; let the oblong Image of the Sun fall upon the Vertical Priſm C C, which is alſo moveable about its Axis; as the Rays go thro' it, let it be turn'd about its Axis, and left fix'd where the Rays are leaſt of all turn'd out of the Way by Refraction thro' the Priſm: In that Caſe the Rays are refracted in the ſame Manner thro' this Priſm as thro' the firſt, but they are not diſpos'd the ſame Way, for that wou'd form a ſquare Image. But here the Image, keeping the ſame Breadth, is inclin'd at R V, the Rays at V being moſtly turn'd out of the Way, as in the Refraction thro' the firſt Priſm B B.

The Demonſtration, before given *, *of the conſtant and ſettled Ratio between the Sines of the Angles of Incidence and Refraction, may be referr'd to any homogeneous Rays*; but conſidering the different Refrangibility of the Rays, this Proportion varies, as it follows from the Experiments of this Chapter. 856 * 639

But *the Refrangibility in all the different Sorts of Rays is every Way unchangeable*, as will appear by the Experiments to be mention'd hereafter. 857

CHAP. XIX.

Concerning the Colours of the Rays, and their Unchangeableneſs.

858 *THE different Refrangibility of the Rays goes along with the different Colours; and every Sort of Rays, as they are more or leſs inflected by Refraction, have a particular Colour of their own, and which is wholly unchangeable.*

In Reſpect of the Colours, the ſame Thing is to be obſerv'd, as has been taken Notice of in regard to other Senſations *; the Colours are Ideas which have nothing common with the Rays, by which they are excited: Therefore we muſt define what we mean by colour'd Rays and colour'd Objects.

* 502 580, 6

DEFINITION I.

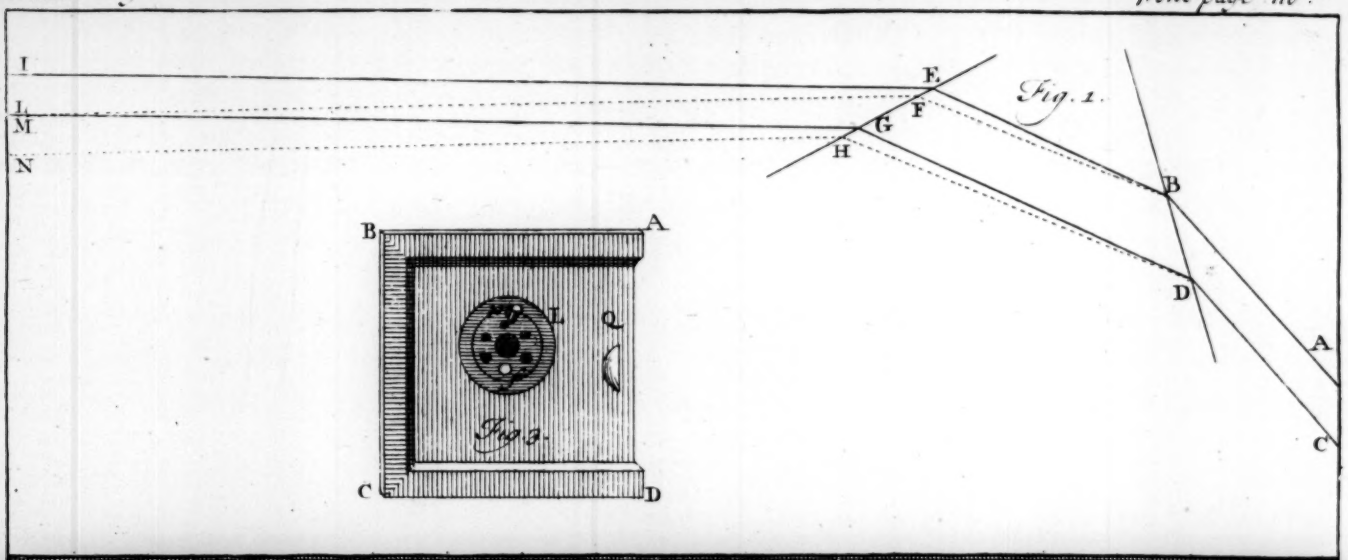
859 *An Object is ſaid to be of ſuch a Colour, whoſe Idea is excited in the Mind by the Rays reflected from the Object.*

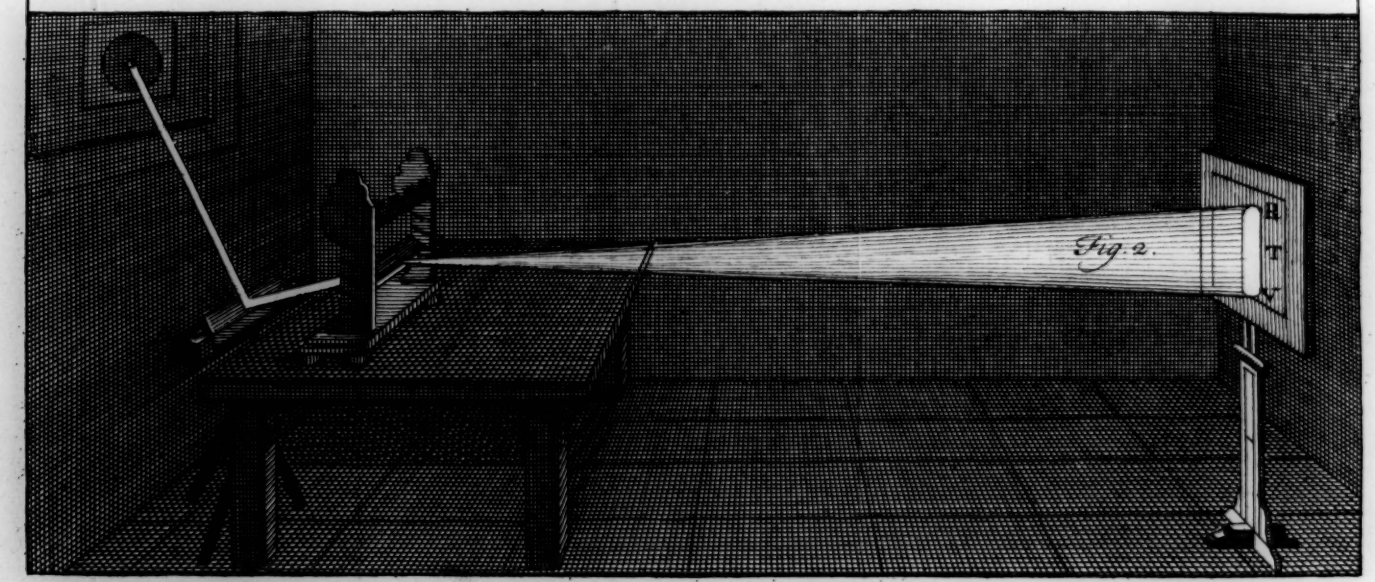
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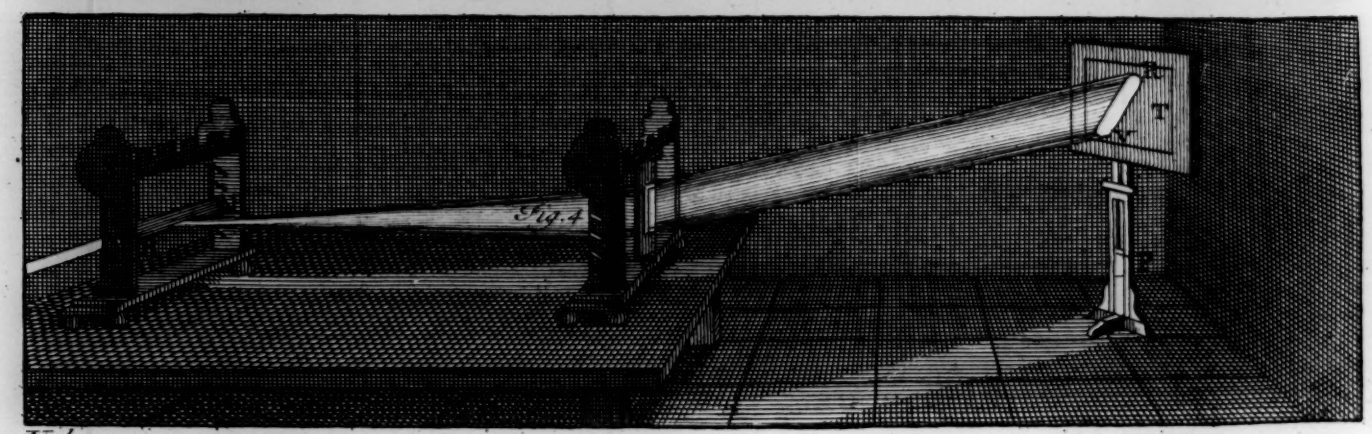
860 *Homogeneous Rays, which, ſtriking upon the Retina, excite in our Mind an Idea of any Colour, are call'd Rays of that Colour.*

We have ſaid that the Rays excite an Idea, by which we underſtand that the Rays put the Fibres into a trembling Motion, and that Motion occaſions an Idea in the Mind.

Plate XVI. *Fig.* 1.] It is very evident from the Experiments of the foregoing Chapter, that Rays of different Refrangibility have a different Colour; for thoſe Experiments ſhew that the Image of the Sun, which is oblong, is tinged

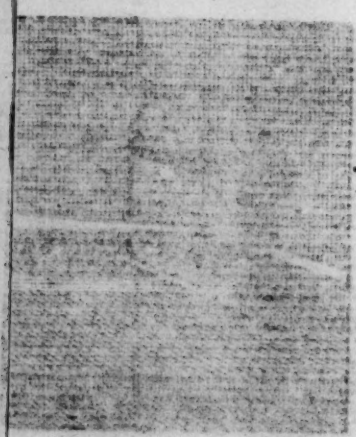






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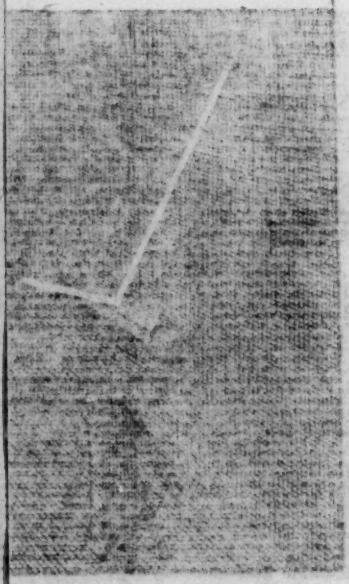


tinged with different Colours. *The Rays, which* 861
are leaſt turn'd out of the Way by Refraction, are red; the reſt of the Colours are in the following Order, namely Orange, Yellow, Green, Blue, Purple, and Violet, of which laſt Colours are the Rays that are moſt refracted *. The oblong Image of the Sun above-mention'd, as has been ſaid *, is * 853
made up of an innumerable Quantity of round Images; if their Diameters be diminiſh'd (which is done by intercepting the Sun's Rays, ſo that only thoſe that come from the Center of the Sun ſhall paſs thro' the Priſm) the Centers of the particular Images which make up the oblong Image will not be chang'd; and therefore the Length of the Image *a h*, between parallel Lines, is not chang'd: And this alone wou'd remain the ſame, if the Breadth of the Image, ſhou'd be infinitely diminiſh'd: And therefore this Length alone is to be conſider'd in determining the Limits of the Colours in the Image itſelf; theſe Colours are repreſented in this Figure by the Letters *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, and the Number which is ſet down againſt each Colour denotes the Space taken up by it in the Image, the whole Lenth of the Image being divided into 360 Parts.

If the Breadth of the oblong Image of the Sun be 862
diminiſh'd, the heterogeneous Colours are more ſeparated in the Image; becauſe there are fewer particular Images confounded in the ſeveral Points, where Rays of different Refrangibilities differ little from each other.

The Colour of any Ray, as alſo its Refrangibility, 863
cannot be changed by any Refractions, or Reflexions, or mingling of the Rays together.

In this Chapter I ſhall ſpeak of Reflexion and Refraction, and of the Mixture of Rays in the following one.





tinged with different Colours. *The Rays, which* 861
are leaſt turn'd out of the Way by Refraction, are red; the reſt of the Colours are in the following Order, namely Orange, Yellow, Green, Blue, Purple, and Violet, of which laſt Colours are the Rays that are moſt refracted *. The oblong Image of the Sun above-mention'd, as has been ſaid *, is * 853
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cannot be changed by any Refractions, or Reflexions, or mingling of the Rays together.

In this Chapter I ſhall ſpeak of Reflexion and Refraction, and of the Mixture of Rays in the following one.

864 That the Refrangibility is not chang'd, by Refraction, is prov'd by the *5th* Experiment of the foregoing Chapter; which may alſo be referr'd to Colour; but is more clearly evinc'd by the following Experiment. Concerning which it is to be obſerv'd (as may be alſo ſaid of what follows) that the Experiments are to be made with Priſms of clear Glaſs, free from Veins; for they occaſion the Light to move irregularly; and the Rays are not duly ſeparated by the Refractions.

Experiment 1. *Plate* XVI. *Fig.* 2.] Every Thing being as in the firſt Experiment of the foregoing Chapter, you muſt make the Experiment with a Sun-Beam, going thro' an Hole of half an Inch Diameter: The Frame or Stand S, in which the Priſm is, muſt be ſuch, that the little flat Board *t*, to be us'd in this Experiment, may move between its Sides; this Board has an Hole F of $\frac{1}{8}$ of an Inch Bore, thro' which the Light refracted by the Priſm is tranſmitted, whereby the Rays in the oblong Image are better ſeparated from one another, the Rays being moſtly intercepted; this oblong Image R V, at the Diſtance of 10 or 12 Feet from the Priſm, falls upon the Board *t* of a Stand like the former; in which Board alſo there is a ſmall Hole F like that in the firſt; thro' this the Rays paſs upon a ſecond Priſm laid upon this Stand, and are refracted in the ſame Manner as in the firſt. By moving the firſt Priſm a little about its Axis, the Image R V aſcends or deſcends, whereby the different Rays are ſucceſſively tranſmitted thro' the Hole; in every Caſe, the Rays refracted thro' the ſecond Priſm, and ſtriking upon the flat Board T which is cover'd with white Paper, are not diſpers'd at H; but the Image is round, if the Rays fall perpendicularly upon the Paper, and alſo of the ſame Colour

Colour as the Rays falling upon the ſecond Priſm. Yet the Image H is ſo much the more lifted up, as the Rays, by Refraction thro' the firſt Priſm, are more turn'd out of the Way; that is, thoſe, that are moſt refrangible in the one Caſe, do alſo ſuffer the greateſt Refraction in the other.

It will appear alſo by the following Experi- 865
ments, that the Refrangibility and Colour are not chang'd by Reflexion.

Experiment 2.] The Rays which, for Example, make the red Part of the oblong colour'd Image, whatever Body they are reflected from, are always red; that is, all Bodies appear red in that Light: In the violet Light they are violet; green in the green; and ſo on in the other Colours.

This will appear by trying it with Vermillion, Orpiment, blue Bice, or Cloth of any Colour, *&c.*

Experiment 3. *Plate* XVI. *Fig.* 3.] Let the Light enter the dark Room thro' two Holes of a Quarter of an Inch Diameter each, in the round Plate moveable in the Window; let theſe Beams be about two Inches aſunder, and reflected by the plane Mirror S.

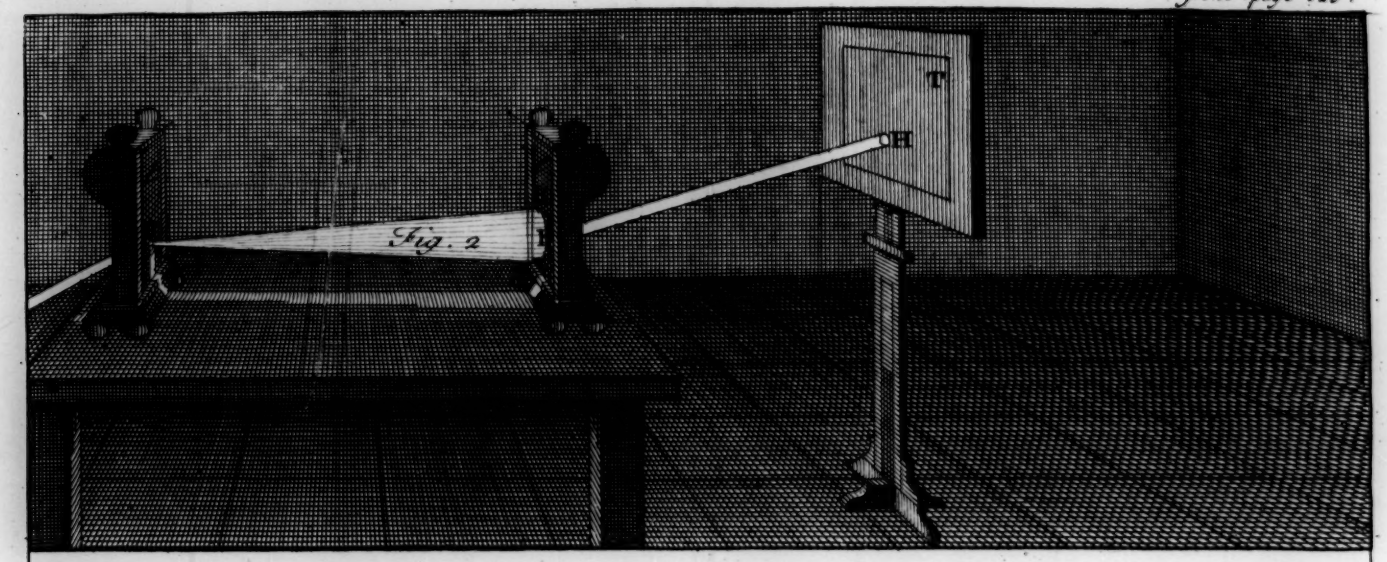
The Plate and Mirror muſt be ſo diſpos'd that the two Beams may fall upon two Priſms A A, which are laid horizontally upon the ſame Frame; ſo that the oblong Image, produc'd by the Refraction of thoſe Priſms, may touch one another at their Sides. Let one Priſm be turn'd a little about its Axis, that the Red of one Image may be juſt on the Side of the Violet of the other: Let theſe Colours, and none of the reſt, be intercepted by a wooden Ruler that has a white Paper paſted upon it, ſo that the

Red be at R, and the Violet at V, the reſt of each Image falling upon the Wall, which muſt be cover'd with a black Cloth. If any Perſon ſtand at O, and thro' the Priſm B B looks at thoſe Colours, R and V, (in the Manner deſcrib'd concerning the Hole, in *Experiment* 4. of the foregoing Chapter) he will ſee the Colours ſeparated from one another, the Red at *r*, and the Violet at *v*; which therefore, being reflected in going thro' the Priſm B B, undergoes a greater Refraction.

In the firſt Experiment of this Chapter we gave a Method, whereby to ſeparate the heterogeneous Rays better than in other Experi-
866 ments; in the following Experiments, Lights of divers Colours become much more homogeneous, which is requir'd in the ſixth Experiment of this Chapter.

Experiment 4. *Plate* XVII. *Fig.* 1.] Let the Sun's Light enter the dark Room thro' an Hole of $\frac{1}{8}$ of an Inch; the Sun Beam muſt be reflected by the Priſm A A to the convex Lens V, which ſtands upon a Foot, and is about 3 or 4 Inches wide; the Length of the incident and reflected Rays, taken together, is about ſeven Feet; the Convexity of the Lens is ſuch, that the Foci of the Rays coming from the ſeveral Parts of the Hole, at the Diſtance of 10 or 12 Feet from the Lens, will form the Repreſenta-
*711 tion of the Hole, if a Paper be held there *. Juſt beyond the Lens place the Priſm B B, whereby the Rays (as in the firſt Experiment of the foregoing Chapter) are diſpers'd; now placing the flat Board T, at the Diſtance at which the Rays, coming from the ſeveral Points, are collected, there will fall upon it a well terminated oblong colour'd Image R V, whoſe Length

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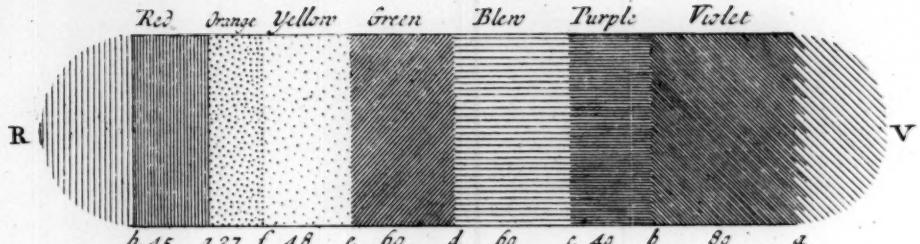
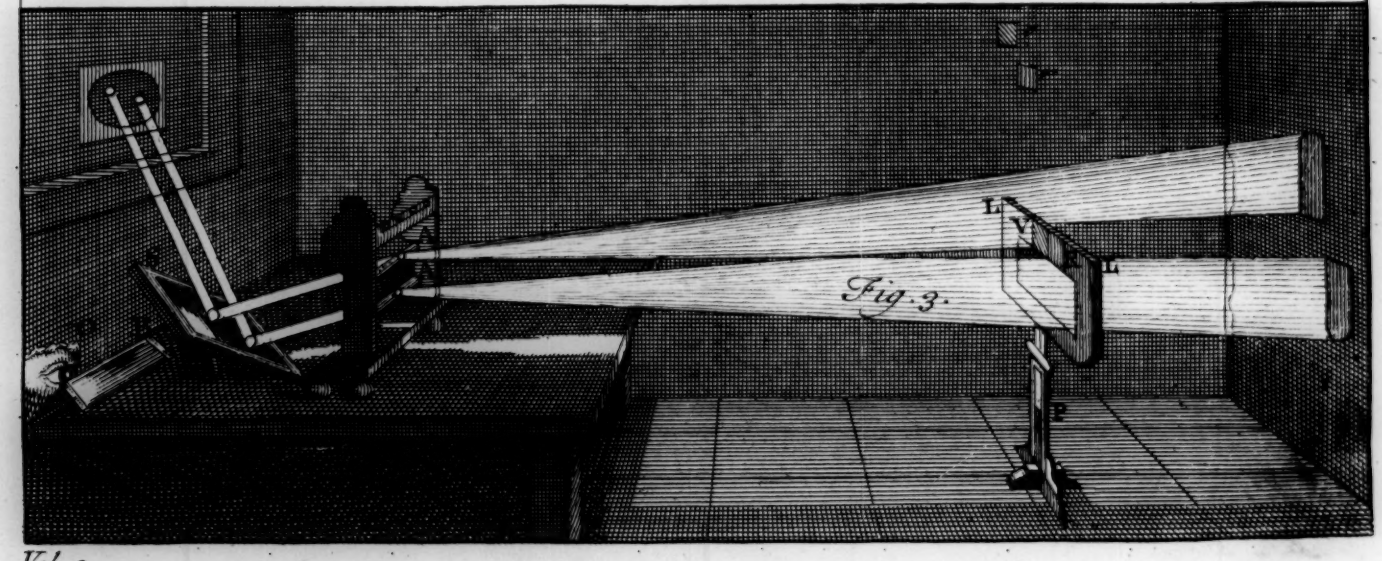
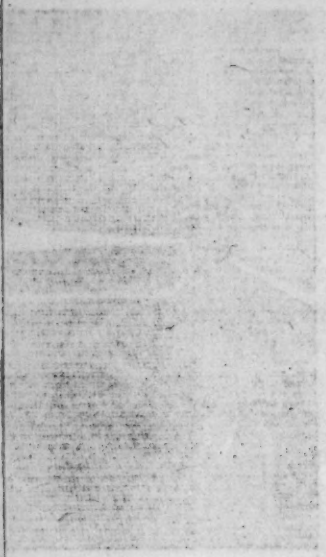
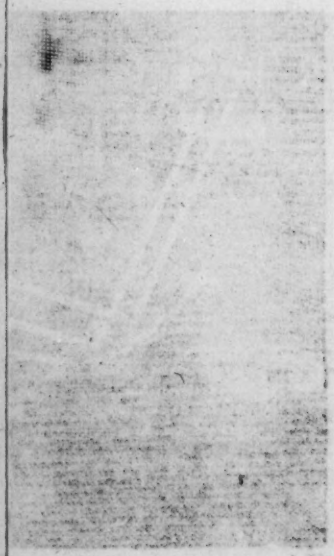


Fig. 1.







Length will have a greater Proportion to its Breadth than in other Experiments; and which therefore is made up of Rays more homogeneous *; and ſo much the leſs mix'd, as the Hole in the Window is the leſs. By moving forward or backward the Board T, one may find the Diſtance at which the Image is moſt diſtinct and terminated without the Penumbra. * 862

Now that the Rays, ſeparated in this Experiment, are homogeneous enough, is prov'd from this, that they can be no more diſpers'd by a new Refraction: And that this is the Property of homogeneous Rays, follows from their equal Refrangibility; which has been already confirm'd by an Experiment *, and is more fully demonſtrated by the following one. * 864

Experiment 6.] Take two Circles of Paper of an Inch Diameter each, and let Light fall upon them in ſuch a Manner, that the one may have the homogeneous Rays of any Colour fall upon it, and the other may be enlighten'd by the Rays of the Sun; if both theſe Papers be look'd at thro' the Priſm at the Diſtance of ſome Feet, as in the third Experiment of this Chapter, the Circle, enlighten'd by the heterogeneous Light, appears oblong, and ting'd with different Colours, as in the fourth Experiment of the foregoing Chapter; but neither the Colour nor Figure of the other Circle is chang'd.

Experiment 6.] Upon a white Paper draw black Lines parallel to one another, and about the ſixteenth Part of an Inch wide; let theſe be enlighten'd by throwing upon the Paper the oblong Image, which is deſcrib'd in the fourth Experiment, ſo that the Lines may lie long-wiſe in the Image. Beſides this you muſt have a con-

vex

vex Lens, about five or ſix Inches wide, ſuſtain'd upon a Foot, ſuch as are repreſented at V (*Plate* XIX. *Fig.* 2.) which collects the red Rays that come from a radiant Point, ſix Foot diſtant from the Glaſs, at an equal Diſtance on the other Side. If this Lens be plac'd at the Diſtance of ſix Feet from the Image above-mention'd, the Parts of the black Lines that are enlighten'd by the Red falling upon the Paper, by means of the Rays which are collected by the Lens, will be exactly repreſented in the red Image at the Diſtance of ſix Feet; but you muſt bring the Paper forward about three Inches and a Half, to make thoſe Parts in the Lines which are enlighten'd by the Purple, to appear diſtinct in that Part of the Image which is of the ſame Colour: The intermediate Colours give Images at intermediate Diſtances; the Violet is ſo weak, that the Threads cannot be repreſented in it.

This Experiment does alſo confirm, that the Colour of reflected Rays is not chang'd by a new Refraction thro' the Lens; as alſo that the moſt refrangible Rays are more inflected than the others in paſſing thro' the Lens.

867 This laſt Experiment does alſo prove, *that the different Refrangibility of the Rays is the Cauſe that hinders the Perfection of Teleſcopes.* For the Foci of the Points, that are equally diſtant, fall at different Diſtances from the Lens, according to their different Colours; whence all the Repreſentations of the Points are unequally diſtant from the Eye-Glaſs; and therefore they cannot be all perfectly ſeen thro' it.

868 Concerning the Reflexion of the Rays it is to be obſerv'd, that *thoſe Rays are more eaſily reflected totally, which have the greateſt Refrangibility*; for the greater is the Refraction of the Rays, the

the leſs Obliquity is requir'd to make them be totally reflected*. *793

Experiment 7. Take a Priſm, plac'd as before*, in the Experiment where it was obſerv'd, *790 that by moving the Priſm about its Axis, the Rays that firſt went thro', when their Inclination is increas'd, become wholly reflected; but if the Priſm be gently mov'd in this Caſe, we ſhall perceive that the violet Rays are the firſt which will be wholly reflected, then the purple Rays, and all the reſt in the ſame Order, as they are in the oblong Image of the Sun, ſo often mention'd; which appears, if the reflected Rays be ſeparated by the Refraction of the Priſm.

CHAP. XX.

Of the Mixture of Colours, where we ſhall ſpeak of Whiteneſs.

THAT the Refrangibility and Colour of 869
the Rays are not chang'd, by the Mixture of Rays of different Refrangibility, has already been ſaid*, and now we muſt prove it by Expe- *863
riments.

Experiment 1. *Plate* XVI. *Fig.* 3.] This Experiment muſt be made in the ſame Manner as the third of the foregoing Chapter; here you muſt make the Red R, and the Violet V be confounded and mix'd together, by throwing them upon the ſame Part of the Ruler L L, which thereby will appear of a purple Colour in that Place. But if a Perſon looks at them thro' a Priſm, the Colours will appear ſeparated; and therefore neither the Colour nor Refrangibility are chang'd by this Confuſion of Colours.

Experiment 2. *Plate* XVII. *Fig.* 2.] If the oblong colour'd Image of the Sun (of which Mention was made in the firſt Experiment of the 18*th* Chap.) falls at R V upon the convex Lens L, mention'd in *Experiment* 4, of the foregoing *Chap.* which muſt be placed at ſix or ſeven Foot from the Priſm B B, the divergent Rays will converge by the Refraction of the Lens, and interſect one another at the Diſtance of 9 or 10 Feet at A; if the Board T be placed at a greater Diſtance, the Rays, which diverge again after the Interſection, will fall upon it diſpers'd; and you will again have an oblong colour'd Image; but the Colours by reaſon of the Interſection at A, will appear in a contrary Order, and will not be chang'd by having been mix'd together at A.

Experiment 3. *Plate* XVII. *Fig.* 2.] Every Thing ſtill remaining as in the former Experiment, if with a black Paper you intercept ſome of the Rays of the Image R V, which changes the Mixture (which this Way may be varied in any Manner) the Colours of the other Rays, that are again ſeparated, are no Way chang'd.

870 *If the Rays of the Sun*, as they come to us, *are wholly reflected by any Body, that Body appears White*; but theſe Rays are an Heap, or Parcel
* 847 of Rays of various Colours *; whence we de-
858 duce, that *a Mixture of different Colours makes a*
871 *Whiteneſs*; for if the Colours which are obſerv'd in the oblong Image of the Sun, ſo often mention'd, be mix'd and confounded together, in the ſame Proportion as they are in that Image, a Whiteneſs will be produced; which alſo proves, that in that Reſpect the Rays are unchangeable. The Rays that come from the Sun appear white;

white; but, if they are ſeparated, their Colours are diſcover'd; and, if they be mix'd again, the Whiteneſs will be reſtor'd.

Experiment 4. *Plate* XVII. *Fig.* 2.] Things being diſpos'd as in the two foregoing Experiments; let the Board T be plac'd at A, in the very Place where all the Rays of the Image R V are confounded together; there will be a Whiteneſs at A; if with a black Paper you intercept the Red of the Image R V, the White will vaniſh, and the Colour at A be bluiſh; but if you intercept the violet and blue Rays, the White becomes reddiſh.

Experiment 5. *Plate* XVII. *Fig.* 3.] Take three triangular Priſms, made of Wood and Plates of Glaſs which contain Water, as B B, D D, D D; the Plates of Glaſs in each of them make an Angle of about 70 Degrees: The Length of the Plate is of ſix or ſeven Inches, and their Breadth of three Inches; theſe Plates are fix'd in another Manner in the Priſms D D, D D, than in the Priſm B B, ſo as to make their Baſes bigger, that is, theſe Priſms are ſhorter and deeper than the other. Let the Sun's Rays be refracted thro' the Priſm B B, as in the 3d *Experiment* of the 18*th Chap.* And let the oblong Image of the Sun at the Diſtance of three or four Foot fall upon the Surface of the Priſm D D, plac'd parallel to the Surface of the Priſm B B, out of which the Rays go. In the ſecond Priſm the Rays undergo a contrary Refraction than in the firſt; becauſe of the Parallelliſm above-mention'd: And becauſe the Edge of the Angle, form'd by the Glaſs Plates in the Priſm B B, is turn'd upwards, and that of D D downwards; therefore the firſt Refraction is deſtroy'd by the ſecond, and the Rays go out of the Priſm D D parallel to one another,

another, and fall upon R V; for if the Prisms be brought together, so that the parallel Surfaces may touch one another, the Light will pass thro' a Medium terminated with parallel Planes, (which is form'd by the two Prisms join'd together) thro' which Light, of any Degree of Refrangibility, will pass without Change of Di-
* 628 rection*. Now the Prisms are separated, that the heterogeneous Rays may be separated, before they again become parallel; if these colour'd Rays fall upon the third Prism D D, and in passing thro' it undergo a Refraction like that which they have undergone in passing thro' the first or second Prism; the Rays that go out at *r v* converge, on account of unequal Refractions in Rays of different Colours, and concur at A, in which Place also Whiteness will be produc'd, as in the foregoing Experiment.

Experiment 6.] If an oblong colour'd Image of the Sun be made, after the Manner describ'd in *Experiment* 1. of the 18*th Chap.* and a Person standing at the Distance of the Prism, that refracts the Light, looks at the Image thro' the said Prism, as was done in respect of the Hole in the fourth Experiment of the same Chap. he will see a round and white Image; the second Refraction destroying the first; for thereby the Rays, being again mix'd, enter the Eye, and in this Case make the Object appear white.

872 *The Mixture of all the Colours, which are observ'd in the oblong Image of the Sun, is not necessary for producing White:* The Whiteness of the Sun's Rays is a little inclin'd to yellow; and therefore if Part of the yellow Rays be taken out of the Mixture, the White will be the more perfect. From the Mixture of four or five Colours, in a just Proportion, White will be produc'd.

Pri-

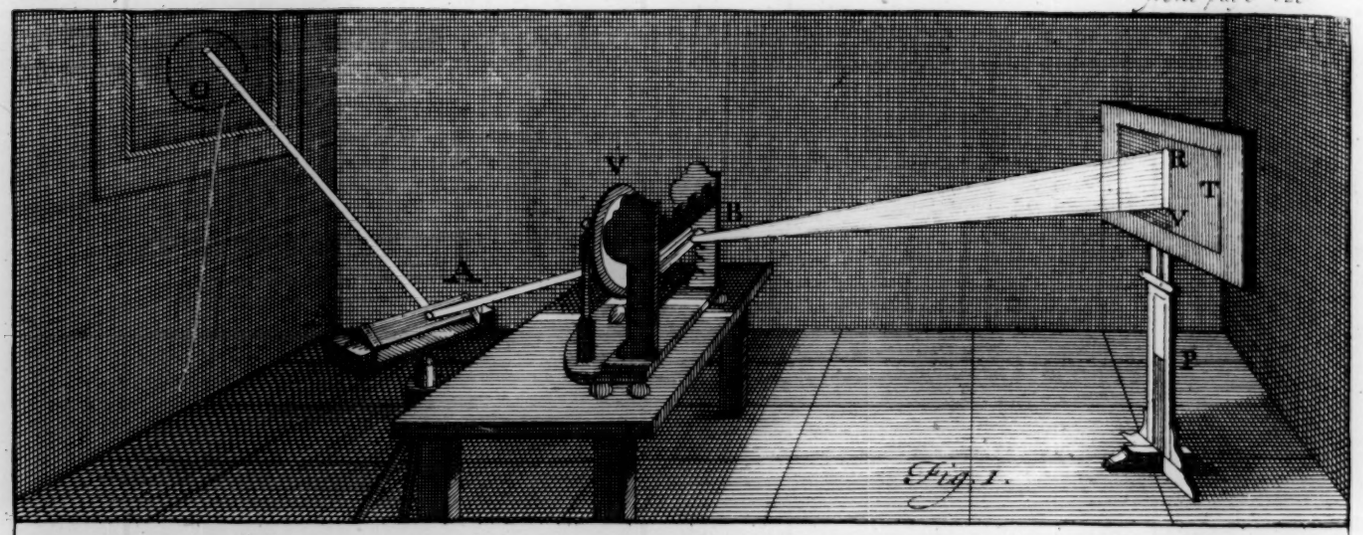


Fig. 1.

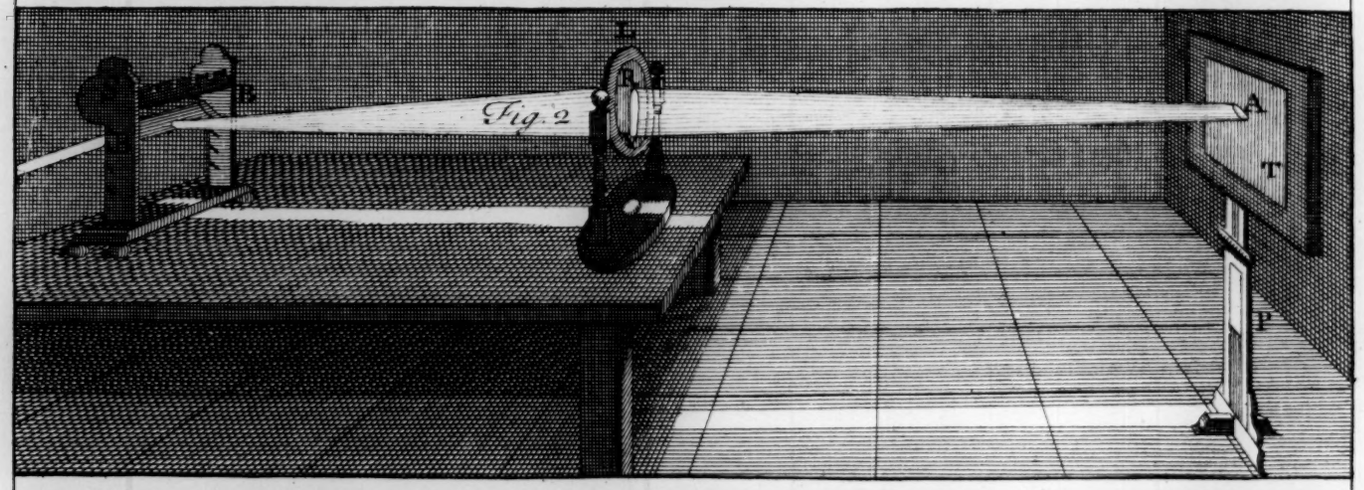
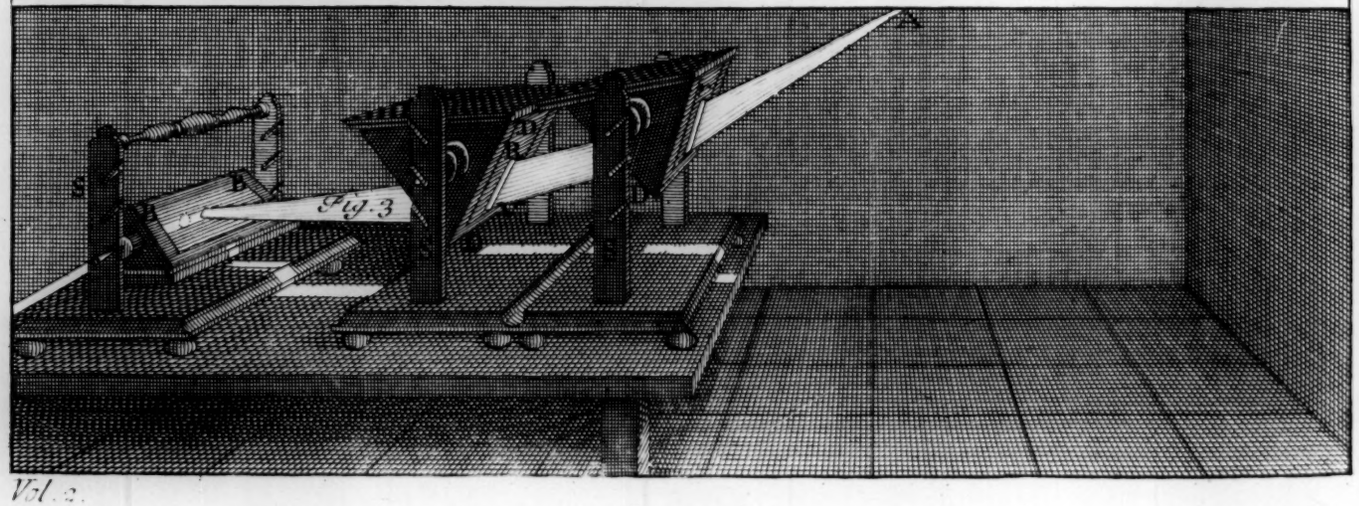


Fig. 2





Primary, that is, homogeneous, *Colours, being mix'd, produce innumerable Colours, different from the primary or homogeneous ones.* From a Mixture of other Colours one may produce a Colour like that which is homogeneous; but *when there can be no Difference obſerv'd by the naked Eye between an homogeneous and a mix'd Colour, one may perceive a ſenſible Difference thro' a Priſm.* 873

Experiment 7.] Thro' a Priſm look at any ſmall Objects, ſuch as Letters upon Paper, Flies, and other ſuch things; if they be expos'd to the common open Light, they will appear confus'd; but if they be enlighten'd by the homogeneous Light of the fourth Experiment of this Chapter, they will appear diſtinct when ſeen thro' the Priſm. 874

CHAP. XXI.

Of the Rainbow.

HAVING made an End of conſidering what relates to the Rays, whereby Bodies are enlighten'd; before we leave this Subject, we muſt explain a Phænomenon, which is too remarkable and common to be paſt by in Silence.

The *Iris* or *Rainbow* is what every Body has often ſeen; we muſt explain what is the Cauſe of it, having firſt laid down ſome Things for that Purpoſe.

Plate XVIII. *Fig.* 1.] *Let there be a denſe Medium encompaſs'd with a rarer, terminated by the Circle* BDFH. *Let homogeneous Rays that are parallel to one another fall upon it*, and let AB be one of theſe Rays; let the Semidiameter CB be drawn and continued to N; it will be perpendicular 875

cular to the Surface ſeparating the Mediums: A B N therefore is the Angle of Incidence; This Angle is equal to the oppoſite vertical Angle CBL, whoſe Sine is CL, perpendicular to BL and going thro' the Center; the Ray is refracted
*624 towards the Perpendicular *, and C B M is the Angle of Refraction, whoſe Sine is C M drawn from C perpendicular to B D: There is the ſame
*639 Proportion between ſuch Lines as CL and CM *, for every Ray, as there is for A B. The Ray B D does in Part penetrate into the rarer Medium in the Direction D E, and is in Part reflected along D F; and makes the Angle of Reflexion
*805 C D F equal to the Angle of Incidence * B D C; whence B D and D F are equal. The Ray D F does alſo in Part go out of the denſer Medium along F G, and is in Part reflected along F H; which in the ſame Manner does in Part go thro' H I, and is in Part reflected: But this Reflexion, and other farther Reflexions and Refractions we ſhall not conſider; they are too weak, on account of the ſeveral Diviſions that the Light has undergone.

Plate XVIII. *Fig.* 1.] The Ray F G, which after one Reflexion goes out of a denſer Medium, makes the Angle G P A with the incident Ray A B, which varies in different incident Rays; therefore, tho theſe Rays ſhou'd be parallel, *they will be ſcatter'd when they go out, after one Reflexion*, as may be ſeen by the ſecond Figure.

The Ray E E, which, being continued, goes thro' the Center C, is not turn'd out of its Way
*806 either by Reflexion or Refraction *.
629 As you recede from this Ray, the returning Ray is continually leſs and leſs inclin'd to the incident one. So the Ray D D, which goes out of a denſer Medium along *d d*, and returns along the Line, makes a greater Angle with *d d*,

than the intermediate Rays between D D and E E do make with their returning Rays, which go out of the denſer Medium.

Let B B be a Ray, in reſpect of which this Inclination is the leaſt of all, that is, which makes the Angle G P A (*Fig.* 1.) the biggeſt of all. Beyond B B the returning Rays are more inclin'd to the incident ones; thus A A returns along *a a*. 876

From this Diſperſion *of the returning Rays* receding from the denſer Medium, they become continually weaker and weaker, and their *Colour cannot be perceived throughout the whole Space which they fill*, tho the Colour of the incident Rays be vivid. *The Colour* in the returning Rays *is only ſenſible, where the neighbouring Rays are parallel*, and thoſe next to them diverge out very little; ſo that at a great Diſtance they are denſe enough to be perceiv'd. *Theſe only are ſaid to be efficacious*, and will be ſuch, when the incident Rays which are near one another, being refracted, concur in the very Point of Reflexion. 877

Plate XVIII. *Fig.* 3.] Let A B, *a b*, be neighbouring Rays parallel to one another, falling upon a circular Surface that terminates a denſer Medium; if theſe being refracted along B D, *b d*, do concur in D the Point of Reflexion, the reflected ones D F, D *f*, will make the ſame Angles with one another as the incident ones D B, D *b*; therefore the refracted Rays F G, *f g*, will be parallel * and efficacious *. In this Caſe the following Method will ſerve to determine the Angle made by the incident Ray with the returning one; that is, the Angle A P G, which here is the greateſt of all. * 627 * 877

Let us call the *Ratio* of I to R, that which is found between the Sines of the Angle of Incidence and Refraction, when the Light goes 878

out of a rarer Medium, by which a denſer is encompaſs'd, into a denſer contain'd in the Circle itſelf. Therefore, having drawn C *m* perpendicular to *b* D, and the Arc *m n* with the Center C and Semidiameter C *m*,

I, R :: CL, CM :: C *l*, C *m* :: CL—C *l* = L *l*, CM—C *m* = M *n*.

Draw B *o* perpendicular to B L, and alſo B *p* perpendicular to B D; and draw *b p*, ſo that it may make a right Angle with B *p*; laſtly, join together by Lines the Points B, C, and M, *m*, the Triangles B *b o*, BCL are ſimilar; for they are rectangular, and the Angles *o* B *b* and CBL (the Difference of each of which from a right Angle is the Angle *o* BC,) are equal.

It may be prov'd in the ſame Manner, that the Triangle BMC and B *b p* are ſimilar; the Triangle M *m n*, which is rectangular at *n*, is alſo ſimilar to this, for the Sides M *n* B *p*, which are perpendicular to the Line B D, are parallel; as alſo M *m* and B *b*, becauſe the Lines BD, *b* D, are biſected at M and *m* into equal Parts. Therefore alſo B *b* is the Double of M *m*, and B *p* the Double of *m n*.

Hence we deduce

BC, BL :: B *b*, B *o*.
BC, BM :: B *b*, B *p*.

Therefore

BL, BM :: B *o* = L *l*, B *p* = 2 M *n* :: I, 2 R :: CL, 2 CM, by comparing theſe Proportions with the aforeſaid Proportion.

Now ſince the Squares of proportional Quantities are themſelves proportional, you will have

$BL^q, CL^q :: BM^q, 4CM^q$.

Whence we deduce

$BL^q + CL^q :: BC^q, BL^q :: BM^q + 4CM^q = BC^q + 3CM^q$, $BM^q = BC^q - CM^q = BL \times LC^q - CM^q$. By

By ſubtracting the firſt and ſecond Term from the third and fourth, (which does not change the Proportion) you will have

BC^q, BL^q, : : 3 CM^q, LC^q—CM^q, : : 3 R^q, I^q—R^q; for there is the ſame Ratio between CM and LC as between R and I.

If therefore you know the Ratio between R and I, you have the Ratio between the Semidiameter BC, and the Line BL, which is the Sine of the Angle BCL, which Angle therefore is given; and by Conſequence you have the Arc BN, and alſo FG, for they are equal.

Having the Sine BL, you have alſo the Sine of the Angle BCM; becauſe (as we have ſhewn before)

BL, BM : : I, 2 R.

Therefore the Arc BD is determin'd, to which DF is equal.

Hence we may eaſily find the Arcs NH and 879
BF; if the former be taken out of the latter, and the Remainder be divided into two equal Parts, we ſhall have, as is well known, the Meaſure of the Angle APG.

When the Ratio between I and R varies, the Angle APG is changed, which therefore becomes different, according to the different Refrangibility of the Rays.

If the aboveſaid Surface be enlightened by hetero- 880
geneous Rays, as they flow from the Sun, *the efficacious Rays of different Colours do not make equal Angles with the incident ones, and* ſo *by the Help of this Refraction the Colours are ſeparated.*

Plate XVIII. *Fig.* 4. *Experiment* 1.] Let the Sun's Light enter the dark Chamber, thro' a Slit in the moveable round Plate O, and being horizontally reflected from the Looking-glaſs S, let it paſs thro' a Slit in the little Board or Stand T;

630 as has been before explain'd. Take a Phiol exactly cylindric, made of clear Glaſs, and full of Water. Let the Beam or Ray at *f g* fall upon the Surface of the Phiol, it will be refracted in the Water towards *h i*, and there reflected, and will go out of the Phiol at *l m*. The Phiol may be eaſily ſo placed, as to make theſe Rays efficacious; and, becauſe of the Breadth of the incident Ray or Beam, efficacious Rays of all Colours will go out of the Phiol in the ſame Time; for they are very little diſtant from one another in their Incidence. If theſe efficacious Rays fall upon a white Paper, at the Diſtance of 4 or 5 Feet from the Phiol, they will produce vertical *Faſciæ* or Pillars, of various homogeneous Colours, ariſing from the efficacious Rays of each Colour; if alſo, the Eye be placed any where at the Diſtance of ſome Feet from the Phiol, as at N, in theſe efficacious Rays, it will ſee in the Phiol that Colour whoſe Rays enter the Eye, and by a ſucceſſive Motion of the Eye, it will perceive all *861 the afore-mention'd Colours.*

881 *Plate* XVIII. *Fig.* 5.] But as to thoſe Rays, which after a double Refraction in a denſer Medium emerge, they will be efficacious, if they are parallel after the firſt Reflexion; for then F H, *f h*, are in the ſame Manner inclin'd to H *h* as B D, *b d*, to B *b*; and therefore ſuppoſing the incident Rays A B, *a b*, to be parallel, the emer-*927 ging Rays H I, *h i*, will alſo be parallel*.

In this Caſe *d* D is Half of the Difference between the Arcs D E and *d f*, or D B and *d b*, but their Difference is B *b* — D *d*; if therefore this laſt be ſubtracted from the other, there will remain the Double of the Arc D *d*, whoſe Triple therefore is B *b*. If by Lines the Points D, *d*, and B, *b*, be join'd, the Triangles B E *b* and D E *d* will be ſimilar, as is known; which there-

fore obtains, tho' the Arcs B*b*, D*d*, be ſo very ſmall, that they may be taken for right Lines.

There is therefore that Ratio between E D and E *b*, which obtains between theſe Arcs, that is, E D is the third Part of E *b*, or E B; becauſe we ſuppoſe the Arc B *b* to be extremely ſmall. M D therefore is divided into two equal Parts at E; and M E is a third Part of E B.

Now if (as in *Fig.* 3.) the Triangles B *o b*, B *p b*, and M *m n*, be form'd, M *m* will be the third Part of B *b*, and B *p* the Triple of M *n*; now if, *mutatis mutandis*, we apply to this Figure what was demonſtrated with reſpect to *Fig.* 3.* * 878
becauſe in this B *p* is equal to 3 M *n*, whoſe Square is 9 M n^q, we ſhall have

B C^q, B L^q : : 8 R ^{q}, I^q—R ^{q}.

From which Proportion, as was ſaid of *Fig.* 3. the Arc B N may be diſcover'd to which H G is equal; and becauſe in this Caſe

B L, B M : : I, 3 R,

You have alſo the Arc B D, to which (becauſe the Angles of Reflexion are equal to the Angles of Incidence) * D F and F H are equal. * 805

From which Things being found, we may 882
eaſily deduce the Arcs G F D N, and B H, whoſe half Difference is the Meaſure of the Angle H P B, which is form'd by the emerging Ray with the incident one; which Angle in this Caſe is the leaſt of all that are like it, and is different according to the different Refrangibility of the Rays. Whence alſo in this Caſe the *efficacious Rays of various Colours, ſuppoſing the incident ones parallel, are ſeparated after a double Reflexion.* 883

Plate XVIII. *Fig.* 4. *Experiment* 2.] This Experiment is perform'd after the ſame Manner as the former, only the Situation of the Phiol muſt

be a little chang'd, that after two Reflexions in the Phiol, the Rays may come to the Eye or Paper towards N.

884 What has been hitherto explain'd, may be applied *to the Rainbow* ; for which Phænomenon *it is requir'd, that Drops of Water ſhould be ſuſpended in the Air* ; *that the Spectator ſhould be placed with his Back towards the Sun, between it and the Drops* ; *and that there ſhould be a dark Cloud behind the Drops*, that the Colours may be more ſenſible, which are ſcarcely perceiv'd, if vivid Light enters the Eye at the ſame Time.

If theſe Things being ſuppos'd, we conceive each Drop to be cut by Planes paſſing thro' the Sun and the Eye of the Spectator ; what has been demonſtrated of a Medium, terminated * 878, with a circular Surface, * may be applied to each 879, of theſe Sections.

880, Now here we ſpeak of Rays that penetrate 881, out of Air into Water. In red Rays, that is, 882, 883. thoſe which are leaſt of all refrangible, the *Ratio* between the Sine of the Angle of Incidence and the Sine of the Angle of Refraction, that is, between I and R, is that of 108 to 81 ; or which is the ſame, of 4 to 3 ; with which Numbers, if the Computation be made, the Angle * 879 APG (*Fig.* 3.) will be 42 Deg. 2 Min. *, and the Angle API (*Fig.* 4.) will be 50 Deg. 57 * 882 Min.* If we ſpeak of the violet Rays, I and R are to one another as 109 to 81 ; which Numbers give the Angles APG (*Fig.* 3.) of 40 Deg. * 879 17 Min*, and API (*Fig.* 4.) of 54 Deg. 7 Min.* * 882

Plate XIX. *Fig.* 1.] Let the Drops be ſuppos'd to be diffus'd in the Air, and enlighten'd by the Sun's Rays, which are parallel to one another, and to the Line OF, that paſſes thro' the Eye of the Spectator. Let the Lines *e* O, EO, *b* O, B O, be conceiv'd to be drawn ; and

let the Quantity of the following Angles be thus, (*viz.*) *e* O F of 40 Deg. 17 Min. E O F 42 Deg. 2 Min. *b* O F 50 Deg. 57 Min. B O F 54 Deg. 7 Min. Theſe ſame Lines with the incident Rays *d e*, D E, *a b*, A B, form Angles that are reſpectively equal to the aforemention'd; therefore, if the Drops be conceiv'd at *e*, E, *b*, B, the violet efficacious Rays, after one Reflexion in the Drop *e*, enter the Eye; and the red efficacious Rays come to the Eye from the Drop E; in like manner after one Reflexion, the other intermediate Colours are obſerv'd between *e* and E, in the above-mention'd Order *. After two * 861
Reflexions in the Drop, the efficacious red Rays come to the Eye from the Drop *b*; and the efficacious violet ones from the Drop B; the intermediate Colours appear between theſe Drops after the ſame Manner as between E, *e*; but they are diſpos'd in a contrary Order, and by reaſon of their double Reflexion are alſo weaker.

Let us conceive a Line at O *e*, to be revolv'd about a fix'd Line O F, preſerving the Angle *e* O F, and to form a Cone or Part of a conic Surface: In every Situation the Line *e* O will, with the Rays of the Sun that are parallel to one another, and to the Line O F, form an Angle of 40 Deg. 17 Min. *If* therefore *the Drops* 885
be diffus'd near Part of the Surface of this Cone at the ſame or different Diſtances, *the Eye will ſee a* violet Arc or Bow: The ſame may be ſaid of the other Colours; and therefore Drops being ſuſpended in the Air, it ſees an Arc or *Bow* of the Breadth *e* E, *ting'd with the homogeneous Colours* before-mention'd *, that are diſpos'd in the * 861
ſame Order as in the Experiments with Priſms; becauſe the heterogeneous Rays are ſeparated as much in the Drops as in the Priſm *. * 852

886 By the ſame Way of reaſoning it is plain *there will be a broader* Arc or *Bow ſurrounding the firſt, in which the ſame Colours will appear in a contrary Order, and weaker.*

Experiment 3.] Hang up a black Cloth in the Light of the Sun; and let a Spectator look at it ſtanding between the Sun and the Cloth; then if Water be made to fall in ſmall Drops between the Spectator and the Cloth, the Spectator will ſee a Rainbow, at leaſt the inner one.

CHAP. XXII.

Of the Colours of thin Plates.

WE paſs on to the Colours of natural Bodies; and before we go any farther, we think it proper to examine thin Plates. Whoever attentively has obſerv'd very thin Glaſs, or Bubbles made of Water thicken'd with Soap, muſt have perceiv'd ſeveral Colours in them. Rays of Light, by Help of a thin tranſparent Plate, are ſeparated from one another, and *ac-*
887 *cording to the different Thickneſs of the Plate, the Rays of ſome Colours are tranſmitted, and thoſe of others are reflected; and the ſame very thin Plate is of another Colour, when ſeen by the tranſmitted Rays, than when ſeen by the reflected ones.*

Experiment 1. *Plate* XVIII. *Fig.* 6.] Take two Object-Glaſſes belonging to long Teleſcopes, AB and CD; and let one of them be laid upon the other; then let them be preſs'd together hard, and in the Middle, where the Glaſſes touch one another, you will ſee a tranſparent Spot, which is incompaſs'd with colour'd Circles. If the Light, reflected by the Air that is between

between the Glaſſes, comes to the Eye at O, there will appear a black Spot; and the Colours, which, as you recede from the Center, are ſo diſpoſed, that by reaſon of the ſame Colours coming over again, they may be referr'd to ſeveral Orders, will be as follows; BLACK, Blue, White, Yellow, Red: VIOLET, Blue, Green, Yellow, Red: PURPLE, Blue, Green, Yellow, Red: GREEN, Red; which Colours are alſo incompaſs'd with other Colours; but, as you recede from the Center, grow continually weaker and weaker.

If the Light paſſes thro' the Glaſs to the Eye at O, the tranſparent Spot which tranſmits all the Rays is White; and by that Series, as you recede from the Center, there will appear Colours, which are alſo referr'd to ſeveral Orders contrary to thoſe above-mention'd: WHITE, yellowiſh Red, Black Violet, Blue: WHITE, Yellow, Red, Violet, Blue: GREEN, Yellow, Red, bluiſh Green: RED, bluiſh Green, which are alſo incompaſs'd with weaker Colours.

Experiment 2.] Blow up ſoap'd Water into a Bubble, to form a thin Plate of Water. Let this be cover'd with a very clear Glaſs, leſt, by the Agitation of the Air, the Colours, to be obſerv'd in that Bubble, ſhou'd be confounded by the Motion of the Water. Such a Bubble, becauſe the Water continually runs down every Way, is very thin at Top, and the Thickneſs in going down is continually increas'd; and for the ſame Reaſon the Thickneſs of the Whole is continually diminiſh'd. Before the Bubble breaks, the Top of it becomes ſo thin, as to tranſmit the whole Light and appear Black. If in that Caſe the Bubble be obſerv'd by reflected Light, when

when it is enlighten'd by the Reflexion of a whitiſh Sky, and the extraneous Light is intercepted by placing any black Body behind the Bubble; the black Spot above-mention'd will appear, and be encompaſs'd with the ſame colour'd Circles, diſpos'd in the ſame Order as about the black Spot in the former Experiment. As the Water deſcends, the Rings are continually dilated till the Bubble burſts.

When the extreme Circumference of the Bubble appears red by the reflected Rays, if it be look'd at ſo as to be ſeen by the tranſmitted Rays, it will appear blue; and generally the Colours produc'd by tranſmitted and reflected Rays, in the ſame Manner as in the foregoing Experiment, are oppoſite to one another.

888 By comparing theſe Experiments, it follows, that *if we increaſe the Thickneſs of a very thin Plate, its Colour will be chang'd*, and *there will be the ſame Changes ſucceſſively, and in the ſame Order, whether the Plate be form'd out of a rarer or a denſer Medium.* For in the Plate of Air, between the Glaſſes, and the watery one in the Bubble, whoſe Thickneſs increaſes as it goes farther from the
889 Middle, the Colours will be in the ſame Order. Yet *in a denſer Plate a leſs Thickneſs is requir'd than in a rarer, to have it ting'd with the ſame Colour.*

Experiment 3.] Every thing being diſpos'd as in Experiment 1. if you wet the Edges of the Glaſſes a little on one Side, the Water will by degrees inſinuate itſelf between the Glaſſes; and there will be obſerv'd the ſame colour'd Circles as in the Air, neither will their Order be changed, but the Circles will be leſs; when the Water is got as far as the Center, all the Portions of the Circles in the Water will be ſeparated from the Portions of the Circles in the Air, and be all reduc'd into a leſs Space. *The*

The Colour of a Plate depends upon its Thickneſs and Denſity, and not upon the encompaſſing Medium. * 885 * 887 * 889

Experiment 4.] If you take a Piece of Iſing-glaſs or Talk, ſo thin as to have it colour'd, the Colours will not be chang'd by wetting it; that is, if inſtead of Air the Plate is incompaſs'd with Water.

The Colour of the ſame Plate is ſo much the more vivid, as its Denſity differs more from the Denſity of the circumambient Medium. 891 This is prov'd by the foregoing Experiment, in which the Colours of the Plate, when wet, are more languid than thoſe of the ſame Plate incompaſs'd with Air. In the third Experiment alſo the Colours are leſs vivid than in the ſecond; in both there is a Plate of Water; but in the ſecond Experiment it is inclos'd with Air, and in the other with Glaſs; but Water and Glaſs differ leſs in Denſity than Air and Water.

If Mediums equally differ in Denſity, the Colours will be more vivid, if the denſer be incompaſs'd with the rarer: 892 For a very thin Glaſs Plate, which is colour'd on account of its Thinneſs, being incompaſs'd with Air, the Colours will be more vivid than in *Experiment* 1. in which a Plate of Air is incompaſs'd with Glaſs.

A Plate of the ſame Denſity, incompaſs'd with the ſame Medium, will reflect ſo much the more Light as it is thinner. 893 *Yet if the Thickneſs be too much diminiſh'd, it does not reflect the Light.* 894 All this is plain from the foregoing Experiments; in the three firſt, the colour'd Circles which are the leaſt, and which are alſo the thinneſt, reflect Light beſt of any; but in the Center, where the Spot is the thinneſt of all, there is no ſenſible Reflexion; as this clearly appears in the ſecond: In the firſt there is alſo a very thin Plate

of

of Air, which does not reflect Light; for the tranſparent Spot in the Center is much bigger than thoſe Parts of the Surfaces of the Glaſſes, which immediately touch by the yielding Inwards of the compreſs'd Parts.

895 *If there are Plates of the ſame Medium, whoſe Thickneſſes are in an Arithmetical Progreſſion of* the Natural Numbers 1, 2, 3, 4, 5, 6, 7, *&c. If the thinneſt of them all reflects any homogeneous Rays, the ſecond will tranſmit the ſame,* the third again will reflect them, *and the Rays will be alternately reflected and tranſmitted*; that is, the Plates whoſe Thickneſſes in the above-mention'd Progreſſion anſwer to the odd Numbers 1, 3, 5, 7, *&c.* reflect the Rays which the others tranſmit, whoſe Thickneſſes anſwer to the even Numbers 2, 4, 6, 8, *&c.*

This Property of the Plates obtains in reſpect of any Sort of homogeneous Rays, with this Difference, that different Thickneſſes are requir'd for different Colours, as has been ſaid be-
887 fore; the thinneſt of all for reflecting Violet, and they muſt be thickeſt for reflecting Red; if the Thickneſſes are intermediate, the Rays of an intermediate Refrangibility are reflected, that
896 is, *as the Refrangibility of the Ray increaſes, the Thickneſs of the Plate, that reflects it, is diminiſh'd.*

Experiment 5.] Let the Experiment be made in a dark Room to produce the oblong Image of the Sun upon a Paper, ſuch as is mention'd in *Experiment* 1. *Chap.* 18. Take two Object-Glaſſes of long Teleſcopes (ſuch as were mention'd in the firſt Experiment of this Chapter) let them be preſs'd together, and ſo diſpos'd, that every ſingle Colour of the Image above-mention'd may be ſucceſſively ſeen in them as in a Looking-glaſs; that is, that the Glaſſes may be

be ſucceſſively enlighten'd by ſeveral homogeneous Rays; which may be done, by gently moving about its Axis the Priſm that ſeparates the Rays to make the oblong Image. The Rings, mention'd in the firſt Experiment, appear, but more in Number, and only of one Colour; by Reaſon of the Unchangeableneſs in homogeneous Rays: * In the Interſtices of thoſe Rings the Rays are tranſmitted, as plainly appears by holding a Paper behind, upon which the tranſmitted Rays will come; the Rings are leaſt of any, when they are violet; then are ſucceſſively dilated, conſidering the following Colours, quite to the Red. The Rings being of any Colour, if you meaſure exactly the Diameters of the Circles that may be conceiv'd to be in the Middle of the Breadth of the Rings, the Squares of their Diameters will be to one another as the odd Numbers 1, 3, 5, *&c.* and meaſuring in the ſame Manner the Diameters of the Circles in the Middle of every one of the Interſtices between the Rings, the Squares of their Diameters will be as the even Numbers 2, 4, 6, *&c.* Now in uſing ſpherical Glaſſes, the Thickneſſes of the Plate of Air, in the Circle above-mention'd, are as the even and odd Numbers. * 863

Definition.

An homogeneous Colour, in a Plate of any Medium, is ſaid to be of the firſt Order, *if the Plate be the thinneſt of all thoſe that reflect that Colour; in a Plate whoſe Thickneſs is triple, it is ſaid to be* of the ſecond Order, *&c.* 897

A Colour of the firſt Order is the moſt vivid of any; and ſucceſſively in the following Orders, in the ſecond, third, &c. *it is leſs and leſs vivid.* * 898 * 893

When a Plate of Air is inlighten'd with heterogeneous Rays, as that between the Glaſſes of

of the Teleſcopes, or any *Plate* like it of any other Subſtance, as in *Experiment* 1. and 2. ſeveral of the Rings ſeen in the laſt Experiment are confounded together, and that Colour is ſeen
899 which is made of their Mixture; for *the ſame Thickneſs of a Plate is often requir'd, for reflecting different Colours of various Orders:* So a Plate, which reflects the Violet of the third Order, does alſo reflect the Red of the ſecond Order, as may be deduc'd from the laſt Experiment, if you attentively conſider it: Therefore in the firſt and ſecond Experiment, the third violet Ring is confounded with the outward Edge of the ſecond red Ring, and purple Colour is produc'd; yet all the Red of the ſecond Order is not abſorb'd, becauſe the red Ring is wider than the violet one.

900 *The more the Thickneſs of a Plate is increas'd the more Colours it reflects, and different ones,* of different Orders. The violet Plate of the tenth Order falls in with the blue one of the ninth Order, and the yellow one of the eighth Order, and laſtly with the red one of the ſeventh Order; and the Colour of the Plate is made up of a Mixture of thoſe Colours.

901 *If* in the firſt and ſecond Experiments *a Spectator look obliquely upon the Plates,* ſuch as that made of Air, and that which is made of Water, the Rings will be dilated as they are ſeen more obliquely, that is, in that Motion of the Eye *the Colour of the Plate* in a determinate Place *is chang'd*; yet the Dilatation is greater in the firſt
902 Experiment; which proves, that *the Colour is more chang'd by the Obliquity of the Rays, if the Plane be incompaſs'd with a denſer Medium, than if it be inclos'd by a rarer Medium.*

Plate XVIII. *Fig.* 7.] The Demonſtration of which Propoſition is eaſily deduc'd from the Laws

Laws of Refraction. Let L and *l* be thin Plates; the laſt incompaſs'd with a denſer, and the firſt with a rarer Medium; let them both be of the ſame Thickneſs: If the Rays A B, *a b*, equally inclin'd to the Plates, fall upon them, there will be at L a Refraction towards the Perpendicular; * on the contrary, at *l* the Rays are refracted from the Perpendicular; * and tho B D and *b d* are equal, *b c* is longer than B C; and therefore there is a greater Change in the Motion of the Light in the Plate *l* than in the Plate L. *The Denſity of the Plate* L *being increas'd, the Medium with which it is incompaſs'd remaining the ſame, there will be a leſs* Difference between B C and B D, and therefore a leſs *Change of Colour*; and *if the refracting Power of the Plate be* ſo *increas'd*, that the refracted Rays (whatever be the Obliquity of the incident ones) ſhall not ſenſibly differ, *there will be no ſenſible Difference in the Colour of the Plate, whatever Situation the Eye is plac'd in.*

* 624 * 625 903 904

Hence we may eaſily deduce, that *the Colour of ſome Plates will vary by changing the Poſition of the Eye, and that the Colour of others is permanent.* 905

CHAP. XVIII.

Concerning the Colours of Natural Bodies.

WHAT relates to the Colours of all Sorts of Bodies may be eaſily deduc'd, from what has hitherto been explain'd.

We have ſhewn that the Rays of Light have Colours peculiar to themſelves and unchangeable, ſo as not to be chang'd by Reflexion. * * 863

Therefore *the Rays reflected from Bodies, according as a greater or leſs Refrangibility is proper to the Colour of the Body itſelf, have a greater or leſs Refrangibility.* 906

Experi-

Experiment 1.] In the Middle of a black Paper fix two ſquare Pieces of Ribbon, the one red and the other violet, which muſt be join'd ſo as to touch one another at their Sides in the ſame Manner as the red and violet Colours in the third Experiment of *Chap.* 19. The black Paper muſt be ſo plac'd, that the Ribbons may be well inlighten'd by the Light that comes into the Room thro' the Window: If a Spectator looks at theſe Ribbons thro' a Priſm, as in the Experiment above-mention'd, the Colours will appear ſeparated in the ſame Manner as in that Experiment.

Experiment 2. *Plate* XIX. *Fig.* 2.] Place the two Ribbons mention'd in the former Experiment at R and V; let the laſt be violet, the firſt red; let them be inlighten'd by the Flame of a Candle; at ſix Feet Diſtance place the convex Lens V; (of which Mention has been made in *Exper.* 6. *Cap.* 19.) at the Diſtance of about ſix Feet, you will have the Repreſentation of the Ribbon R upon a white Paper at *r*; at a leſs Diſtance you will have an exact Repreſentation of the other at *v*. You may determine when the Repreſentations are exact, by binding black Threads upon the Surface of the Ribbons; for theſe Threads appear diſtinctly, where the Repreſentation is exact.

907 That *Bodies have various Colours, becauſe different Rays are reflected from Bodies differently colour'd*; and that *a Body appears of that Colour, which ariſes from the Mixture of the reflected Rays*, may not only be deduc'd from the foregoing Experiments, but may be alſo demonſtrated directly by others.

Experi-

front page 144.

Plate 18.

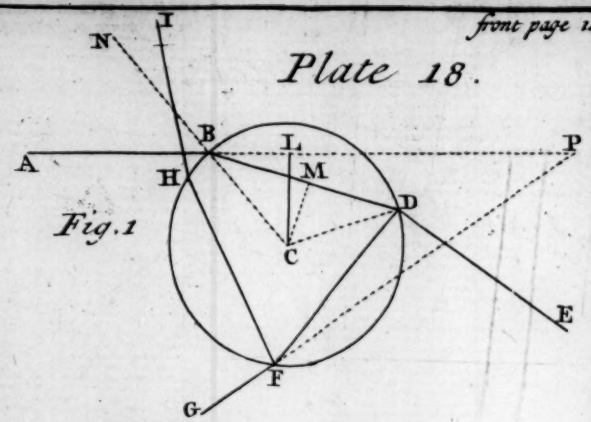


Fig. 1

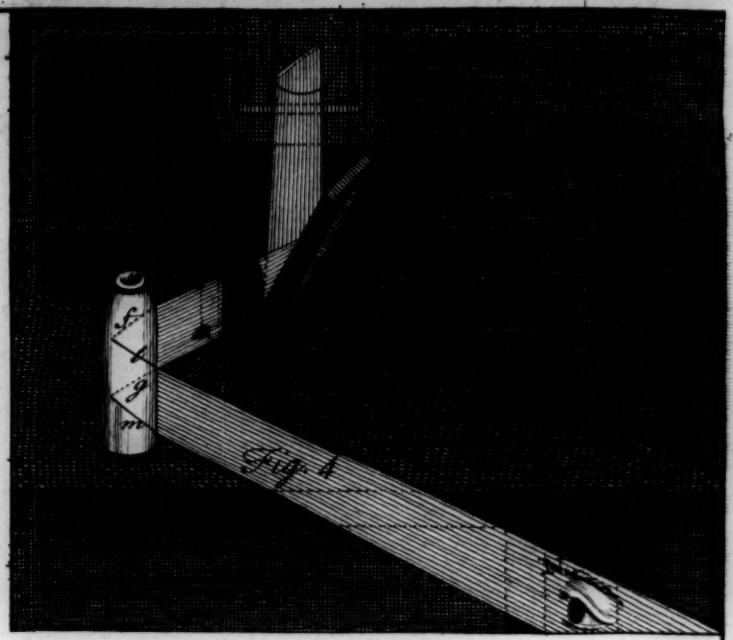


Fig. 4

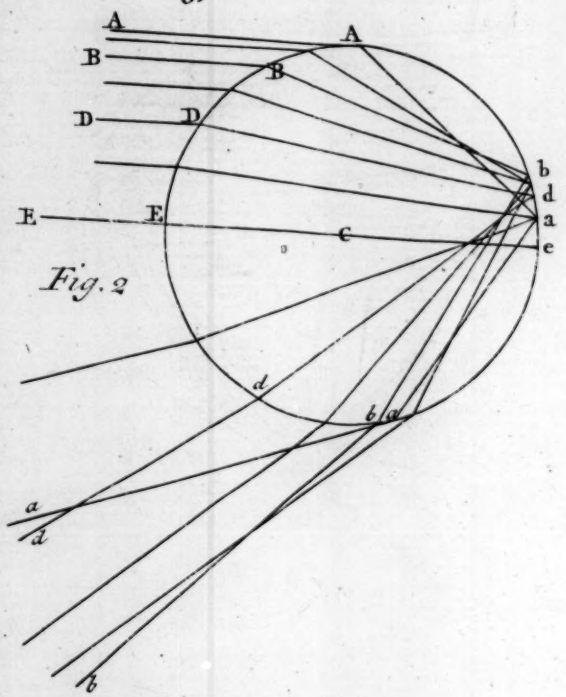


Fig. 2

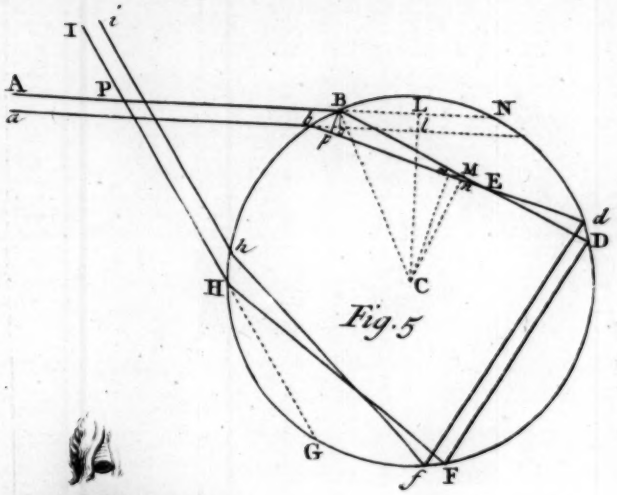


Fig. 5

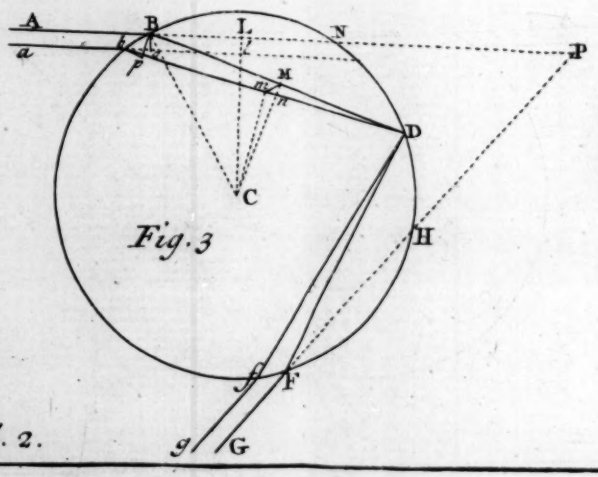


Fig. 3



Fig. 6

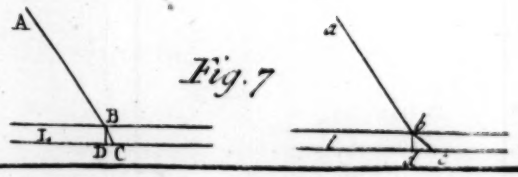
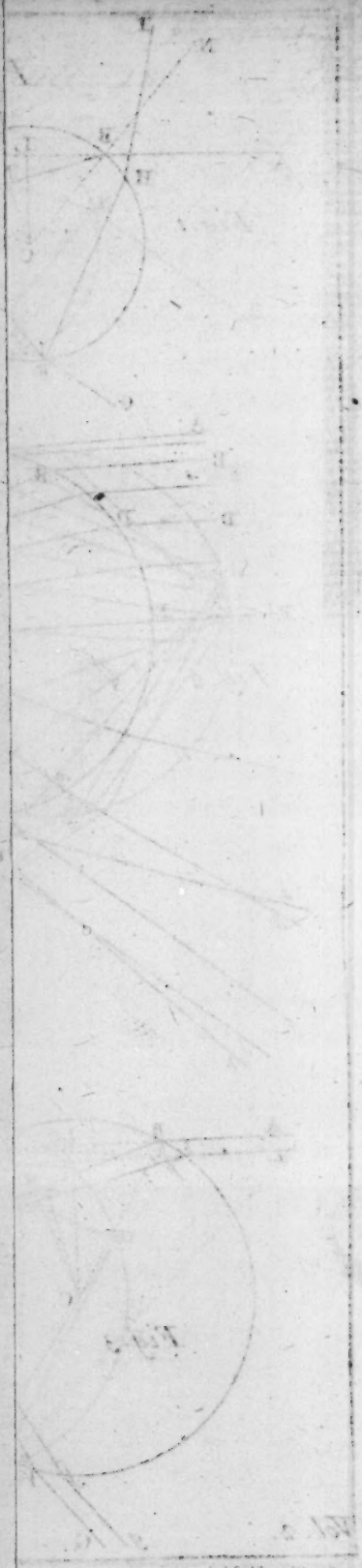


Fig. 7



Experiment 3.] Take two Bodies of any Kind, the one red, the other blue; let them be enlightened ſucceſſively, in a dark Place, by the Colours of the coloured Image, which is made by the Refraction of the Priſm; every one of the Colours will be reflected by both; but the red Rays are copiouſly reflected from the red Body, whilſt the blue Body reflects but few of them, which plainly appears by comparing both Bodies, when they are enlightened by the red; the contrary may be obſerved in blue Colours, which are copiouſly reflected from the blue Body, whilſt only a few are reflected from the red one.

The Rays, which are not reflected from a Body, penetrate into it, and there ſuffer innumerable Reflexions and Refractions, as we have explained between N° 842, and 843; till at length they unite themſelves to the Particles of the Body itſelf.* Therefore *a Body grows hot ſo much the ſooner, as it reflects Light leſs copiouſly.* For which Reaſon *a white Body*, which reflects almoſt all the Rays with which it is enlightened, * *heats the ſloweſt, whilſt a black Body*, into which almoſt all the Rays penetrate, becauſe only few are reflected,* *acquires Heat ſooner than any other.*

*546 908 909 *870 *845

To determine that Conſtitution of the Surfaces of Bodies, upon which their Colour depends, we muſt take Notice of the ſmalleſt Particles, of which theſe Surfaces are made up: Theſe Particles are tranſparent *, and are ſeparated by a Medium of different Denſity from the Particles themſelves; they are alſo thin, otherwiſe the Surface would as it were be covered by a tranſparent Body, * and the Colour would depend upon the Particles under theſe. Therefore in the Surface of every coloured Body there are innumerable ſmall thin Plates; but by

*841 *843 *843

leſſening the Plate, keeping the ſame Thickneſs, its Properties, as to the Reflexion of Light, are not changed; for the leaſt Plate, in reſpect of the Rays of Light, is very large: Wherefore, what has been demonſtrated in the preceding *Chap.* may be applied to theſe Plates in the Surfaces of Bodies. From whence we deduce the following Concluſions.

910 *The Colour of a Body depends upon the Thickneſs*
*890, *and Denſity of the Parts of the Body, which are in*
911 *the Surface, between the Pores of the Body.**
* 898, 899, 900 *The Colour is ſo much the more vivid and homogeneous, as the Parts are thinner.**

912 Cæteris paribus, *the aforeſaid Parts are of the*
*896, 861 *greateſt Thickneſs when the Body is red; and of the leaſt, when violet.**

913 *The Parts of Bodies are much denſer than the*
*902, 903, *Medium contained in their Interſtices.**
904. *This Denſity is leſs in* the Tails of Peacocks, and
914 in ſome Silks, and in general in all *Bodies, whoſe*
*901 903 *Colour varies according to the different Situation of the Eye.**

915 *The Colour of a Body is more obſcure and darker,*
*891 *when a denſer Medium enters its Pores;** for then the Parts, upon which its Colour depends, are ſurrounded by a denſer Medium than before.

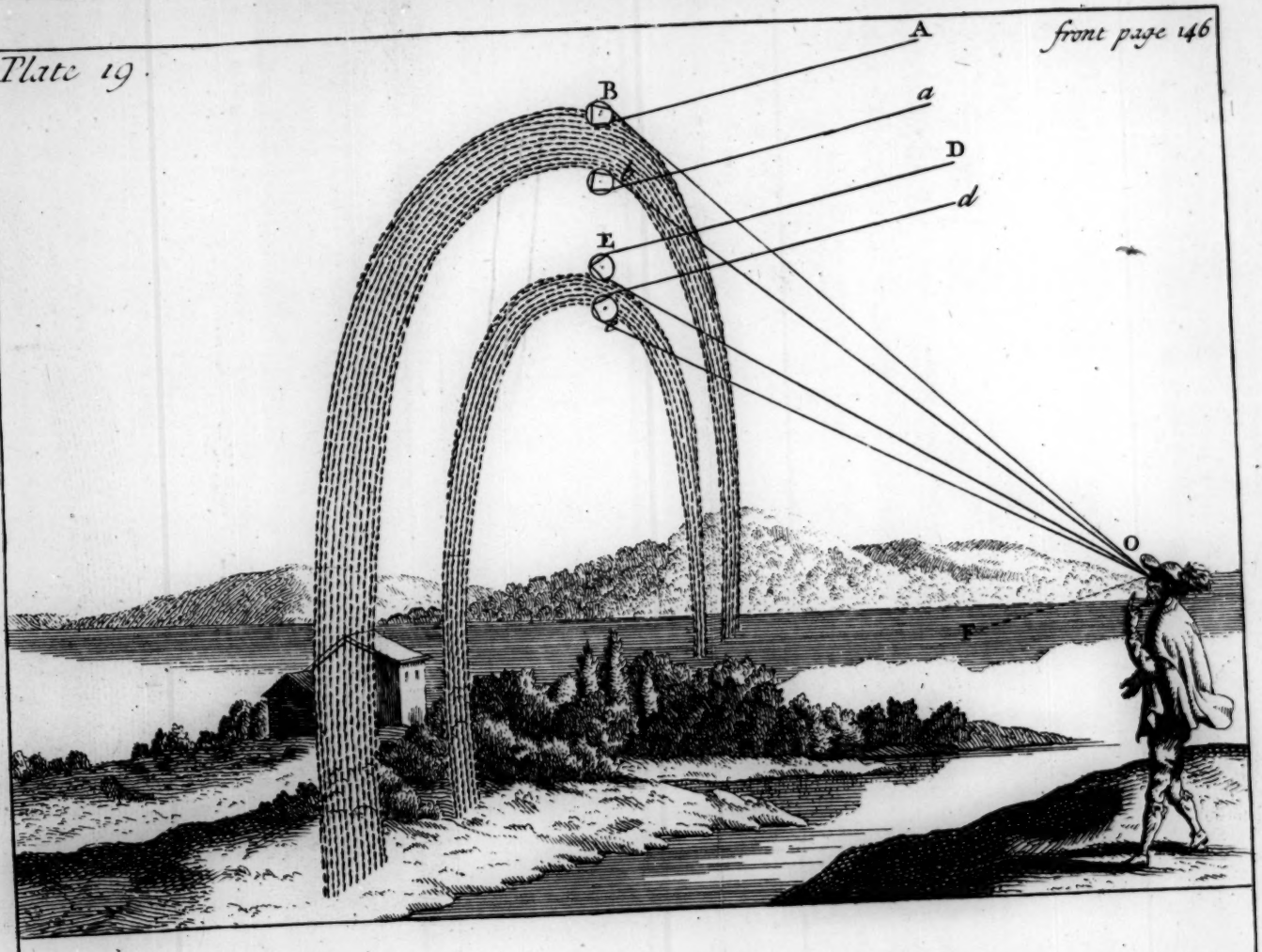
We experience this in all Bodies, which are thoroughly penetrated by Water and Oil: When the Bodies are dry, they recover their former Colour, unleſs in ſome Caſes, in which ſome Parts are carried away by the Action of the Water, or Oil, or when ſome Parts of the Water, or Oil, are ſo united with the Parts of the Body, as to change the Thickneſs of the Plates.

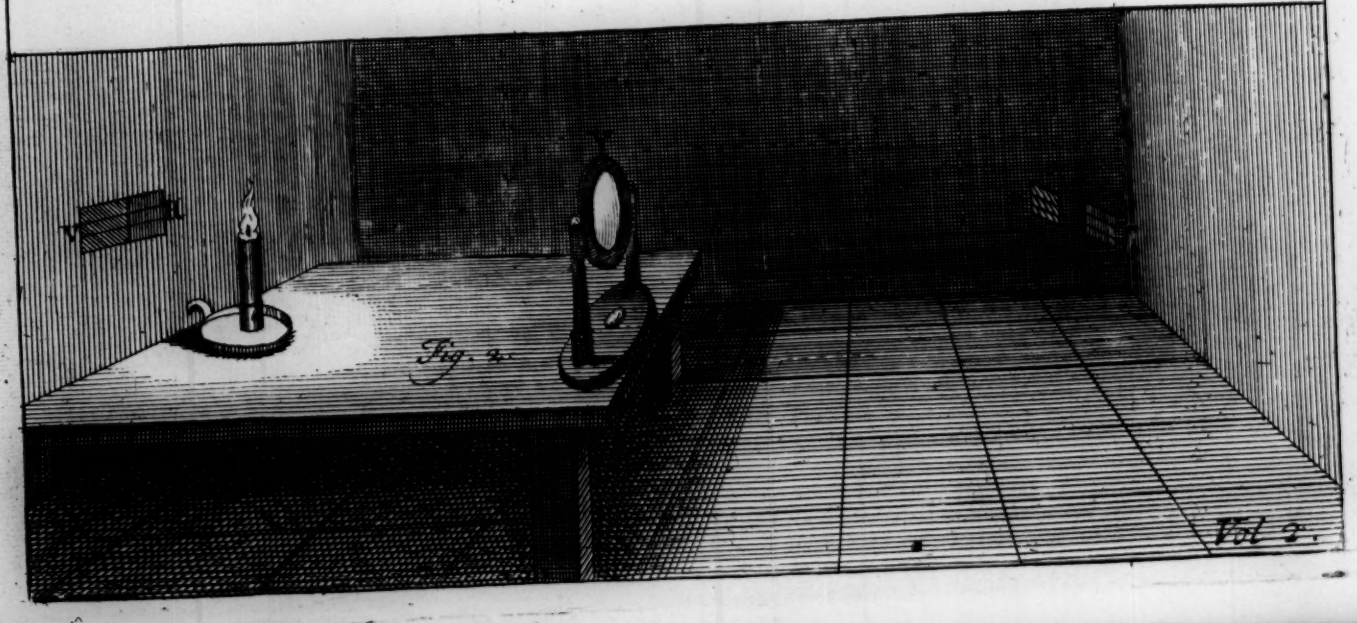
From ſuch a Cauſe are deduced the Changes in the Colours of ſome Liquors, by their being
916 mixed with others. *Often the ſaline Particles, ſwimming in one Liquid, unite themſelves to the ſaline*

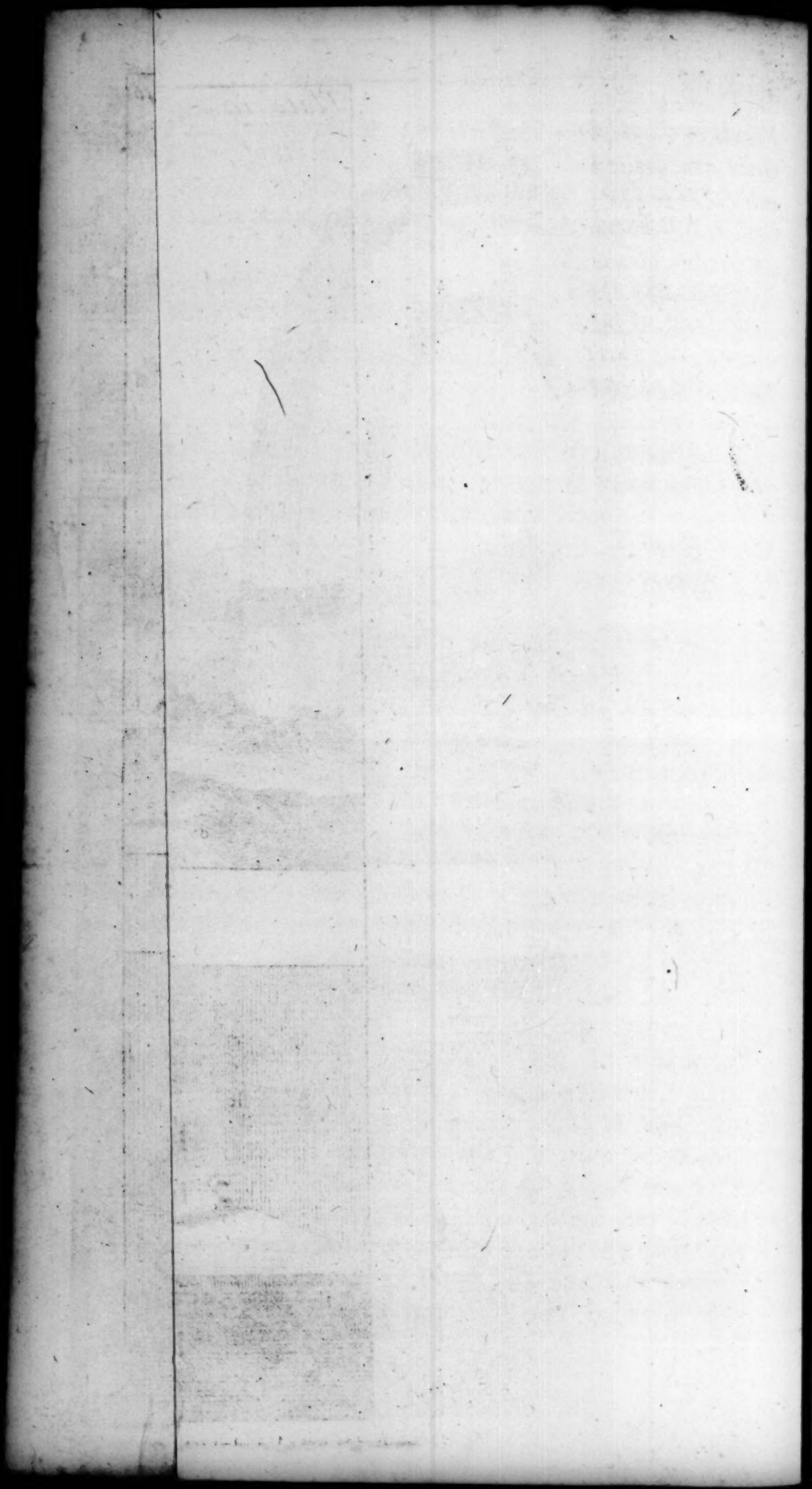
Parti-

Plate 19.

front page 146







Particles ſwimming in another; or *the united Particles are ſeparated by the Actions of others that are ſuperadded*; *on all which Accounts* the Thickneſs of the Particles *is changed*, and together with it *the Colour of the Liquids.** *888

Sometimes the Colour of a Liquid is different, 917
when ſeen by reflected Rays, from what it is, when ſeen by tranſmitted ones: We have ſhewn before whence this ariſes.* *887

Experiment 4.] An Infuſion of *Lignum Nephriticum*, that is not too much tinged, appears blue by reflected Rays, but yellow, if the Phial, which contains the Infuſion, be placed between the Light and the Eye.

Experiment 5.] If you pour Spirit of Vinegar into the Infuſion of *Lignum Nephriticum*, it will appear yellow in any Poſition whatever.

In this Caſe the Thickneſs of the Particles is changed, and the Rays, that were tranſmitted through every one of them, are now intercepted; but though the Liquor is placed between the Eye and the Light, it is ſeen by reflected Rays; for we may eaſily conceive that ſuch Rays come to the Eye by the various Reflexions which the Light undergoes in the Liquid. But this Colour only is ſenſible, becauſe the Rays cannot penetrate directly through the Liquid.

From this we may deduce the Reaſon, why *a* 918
coloured Liquid in a Glaſs, of the Figure of an inverted Cone, if it be placed between the Eye and the Light, appears of a different Colour, in different Parts of the Veſſel; in the lower Part all the Rays which are tranſmitted thro' the Particles, are not intercepted; then they are more and more intercepted, according as there is a greater Quantity of the Liquid between the Eye and the Light; till at

length they come to be all intercepted; and only thoſe Rays which are reflected by the Particles penetrate the Liquid; in which Caſe the Colour coincides with the Colour of the Liquid ſeen by the reflected Rays.

919 *Clouds* often *appear very beautifully coloured*; they conſiſt of aqueous Particles, between which Air is interſperſed; therefore, *according to the va-*
920 *rious Thickneſs of thoſe aqueous Particles*, the Cloud
888 will be of a different Colour.

The End of the Third Book.



Mathe-



Mathematical Elements of *Natural Philoſophy*, Confirmed by EXPERIMENTS.

BOOK IV.

Part I. *Of the Syſtem of the World.*

CHAP. I.

A general Idea of the Planetary Syſtem.

*1 HE who attentively conſiders that Space can be terminated by no Bounds, will ſcarce be able to deny, that the Supreme Almighty Intelligence has every where manifeſted the ſame Wiſdom which He has ſhewn to the Inhabitants of the Earth in a ſmall

Compaſs. What I here call a ſmall Compaſs, immenſly exceeds our Comprehenſion; yet it is but ſmall, compared with infinite Space.

921 *Our Earth, with ſixteen other Bodies* (for we have no Knowledge of any more (*moves in a determinate Space*; neither do theſe Bodies recede from, or come nearer to one another, beyond their ſet Bounds; and their Motions are performed according to unchangeable Laws.

Definition I.

922 *This Collection of ſeventeen Bodies is called the* Planetary Syſtem.

The whole Art of *Aſtronomy* is almoſt employed concerning theſe alone; and theſe will be chiefly my Subject in this Work: The other Bodies that conſtitute the Univerſe, are too far diſtant from us, for their Motions (if they are moved) to fall under our Obſervations: Of theſe only the lucid Bodies can be perceived by us; and of thoſe only the more remarkable ones, and which are leſs diſtant from us than the reſt; even moſt of ſuch as are ſeen by the Teleſcope are inviſible to the naked Eye.

Definition II.

923 All theſe Bodies are called *fixed Stars.*

They are called fixed, becauſe, as far as can be perceived, they keep the ſame Poſition, with reſpect to one another: We muſt take Notice of ſomething peculiar concerning theſe hereafter.

924 But as to the Planetary Syſtem: *In this* we have ſaid *there are* ſeventeen *Bodies, which are all ſpherical: One only ſhines by its own Light, the reſt are opaque, and are viſible only by the Light which they borrow from that.*

925 *The Sun is that lucid Body, and far the greateſt of all in the Planetary Syſtem; it is quieſcent in the mid-*

dle

dle of it, at leaſt is agitated by a very ſmall Motion.

Definition III.

The other ſixteen are called *Planets*.

Theſe are divided into two Claſſes; ſix are called 926
the Primary Planets; *ten are called the* Secondary Planets. When we ſpeak of the Planets, without any Diſtinction, we always underſtand the Primary ones.

The Primary Planets move round the Sun, and are 927
carried at different Diſtances from it, in Curves that return into themſelves.

A Secondary Planet revolves round a Primary 928
one, and accompanies it in its Motion round the Sun.

The Planets in their Motions deſcribe Ellip- 929
tic Lines, not much different from Circles. *And* all *thoſe* Lines *are fixed*; at leaſt, there is but a ſmall Change to be obſerved in a long Time, in their Situation.

Plate XXIV. *Fig.* 3.] An Elliptic Line is 930
formed, if a Thread, whoſe Extremities are fixed in the two Points F and *f*; is moved, remaining ſtretched; as is to be ſeen in this Figure, in which the Thread is repreſented at F *d f*, F E *f*, F B *f*. The Points F, *f*, are called the Foci; the Line A *a*, which paſſes through them, and is terminated on each Side by the Circumference of the Ellipſe, is called the *greater Axis*; and it is the greateſt Line that can be drawn in the Ellipſis. The middle Point C of the Axis is the Center of the Ellipſe; and the *leſſer Axis* D *d* falls perpendicularly through this Point upon the *greater Axis*.

The Orbits of all the Primary Planets are in 931
ſuch a Poſition, that one of their Foci falls in with the Center of the Sun; let the Ellipſe A D *a d*

repreſent the Orbit of a Planet, F will be the Center of the Sun.

Definition IV.

932 *The Diſtance between the Center of the Sun and the Center of the Orbit, is called* the Eccentricity of the Planet; as F C.

933 *In every Revolution the Planet approaches once to the Sun, and once recedes from it*; and at its greateſt Diſtance is at *a*, the Extremity of the greater Axis of the Orbit, and at its leaſt Diſtance, in the oppoſite Extremity A.

Definition V.

934 *That Diſtance of the Planet from the Sun, is called the* mean Diſtance, *which is equally different from the greateſt and the leaſt.* At this Diſtance the Planet is in the Extremities D, *d*, of the ſmaller Axis.

Definition VI.

935 *The Point of the Orbit, in which the Planet is at its greateſt Diſtance from the Sun, is called* the Aphelium; as *a*.

Definition VII.

936 *The Point of the Orbit, in which the Planet is at its leaſt Diſtance from the Sun, is called* the Perihelium.

Definition VIII.

937 Theſe Points are commonly called the *Auges* or *Apſides*.

Definition IX.

938 *The Line which joins the Apſides*, that is, the greater Axis of the Orbit, *is called*, the Line of the Apſides.

Every

Every Orbit is in a Plane which paſſes through the Center of the Sun. 939

Definition X.

The Plane of the Orbit of the Earth is called the Plane of the Ecliptic. 940

This Plane is to be continued every Way; and *Aſtronomers* conſider the Poſition of the Planes of the other Orbits, with reſpect to this.

Definition XI.

The Points, in which the other Orbits cut the Plane of the Ecliptic, are called the Nodes. 941

Definition XII.

The Line which joins the Nodes of any Orbit, that is, the common Section of the Plane of the Orbit with the Plane of the Ecliptic, *is called* the Line of Nodes. 942

A Planet is not carried with an equal Celerity in all the Points of its Orbit; the leſs it is diſtant from the Sun, the ſwifter is its Motion; and the Times, in which the ſeveral Arcs of its Orbit are run thro', are to one another, as the Area's formed by Lines drawn from the Planet to the Center of the Sun: The Arcs A B and *a* E are run through in Times, which are to one another, as the Area's of the mixed Triangles A F B, *a* F E. 943 944

All the Planets are carried the ſame Way, and their Motion in their Orbits is contrary to that Motion which we obſerve daily in all the Cœleſtial Bodies, by which in one Day they ſeem to be carried round the Earth; of which hereafter. 945

Definition XIII.

A Motion, ſuch as is that of the Planets in their Orbits, is ſaid to be in Conſequentia, and direct. 946

Defi-

Definition XIV.

947 *The contrary Motion is called a Motion* in Antecedentia; *and ſometimes* Retrograde.

948 *The more diſtant the Planets are from the Sun, the ſlower they move in their Orbits*; ſo that the periodical Times of the moſt diſtant ones are greater, both becauſe they have a greater Orbit to run through, and a ſlower Motion.

Definition XV.

949 *The Line which paſſes through the Center of the Planet, and about which it moves, is called* the Axis of the Planet.

950 *The Planets*, at leaſt moſt of them, *and the Sun itſelf move round their Axis:* There are Two, of which, in this reſpect, Aſtronomers have been able to make no Obſervations, but which, in all Probability, have this Motion.

951 *This Motion* agrees or conſpires with the Motions of the Planets in their Orbits, that is, it *is* in Conſequentia.

952 *The Axes* themſelves *are moved by a parallel Motion*, ſo that all the Points of the Axis of a Planet deſcribe equal and ſimilar Lines.

Definition XVI.

953 *The Extremities of the Axis are called* the Poles of the Planet.

954 *Plate* XX. *Fig.* 1.] Aſtronomers compare together accurately enough the Diſtances of the Planets from the Sun, to give us an Idea of the whole Syſtem. The Dimenſions of the Orbits are repreſented in this Scheme, in which the Points N N ſhew the Nodes of each Orbit.

955 Nevertheleſs *we cannot compare the Dimenſions of this Syſtem with any that we know upon the Surface of the Earth*; for no Aſtronomers will aſſert,

that

that the Obſervations made concerning ſuch a Compariſon, are free from Error.

But, that the ſeveral Parts of the Syſtem may be compared together, we ſuppoſe the mean Diſtance of the Earth from the Sun divided into 1000 equal Parts, which we make uſe of in meaſuring the other Diſtances. 956

The Sun ☉, as was ſaid before, is agitated by a ſmall Motion in the middle of the Syſtem; it moves round its Axis in the Space of 25 Days: And its Axis is inclined to the Plane of the Ecliptic, making an Angle of 87 Degr. 30 Min. 957

Mercury ☿ is the leaſt diſtant from the Sun of any of the Planets; its mean Diſtance from the Sun is 387, its Eccentricity 80, the Inclination of its Orbit, that is, the Angle, formed by the Plane of its Orbit with the Plane of the Ecliptic, is 6 Degr. 52 Min. it performs its Revolution round the Sun in 87 Days, 23 Hours. 958

The next is *Venus* ♀, whoſe Diſtance from the Sun is 723, its Eccentricity 5, the Inclination of its Orbit 3 Deg. 23 Min. It performs its Periodical Motion in 224 Days, 17 Hours; and its Motion round its Axis is performed in 23 Hours. 959

The third Planet in order from the Sun is our Earth ⊖; its mean Diſtance from the Sun is 1000, its Eccentricity 169: It is moved in the Plane of the Ecliptic; its Periodical Time is 365 Days, 5 Hours, 51 Min. and the Motion about its Axis is performed in 23 Hours, 56 Min. 4 Sec. Its Axis makes an Angle with the Plane of the Ecliptic of 66 Degr. 31 Min. 960

The mean Diſtance of *Mars* ♂ from the Sun is 1524, its Eccentricity 141, the Inclination of its Orbit 1 Degr. 52 Min. Its Periodical Time 686 Days, 23 Hours. Its Revolution 961

about its Axis is performed in 24 Hours, 4[0] Min.

962 *Jupiter* ♃, the biggeſt of all the Planets, is di-ſtant from the Sun, at a mean Diſtance 5201, it[s] Eccentricity 250. The Inclination of its Orbi[t] 1 Degr. 20 Min. The Periodical Time 4332 Days 12 Hours; and its Revolution about its Axis in 9 Hours and 56 Min.

963 The mean Diſtance of *Saturn* ♄, the moſt diſtant Planet from the Sun, is 9538; its Eccentricity 547; the Inclination of its Orbit 2 Degrees 30 Min. The Periodical Time 10759 Days, 7 Hours. It is encompaſſed with a Ring which does not touch the Planet, but never leaves it. This Ring is not viſible without a Teleſcope.

The mean Diſtance being given, if you add the Eccentricity, you will have the greateſt Diſtance; but if you ſubſtract the Eccentricity from the mean Diſtance, you will have the leaſt
836 Diſtance.

964 The three Planets, *Mars*, *Jupiter*, and *Saturn*, which are more diſtant from the Sun than the Earth, are called the *Superior Planets*; *Venus* and *Mercury* are called the *Inferior ones*.

965 *Of the Primary Planets, three are accompanied by Secondary ones.*

Five Planets called Satellites, move about *Saturn*; four about *Jupiter*; one about the Earth (*viz.*) the Moon.

The ſecondary Planets, except the Moon, are not viſible to the naked Eye.

966 *The Satellites, by Lines drawn to the Center of the Primary Planets, deſcribe Area's about them proportional to the Times*; as has been ſaid of the Primary Planets, with reſpect to the Center of the
944 Sun.

The

Plate 20

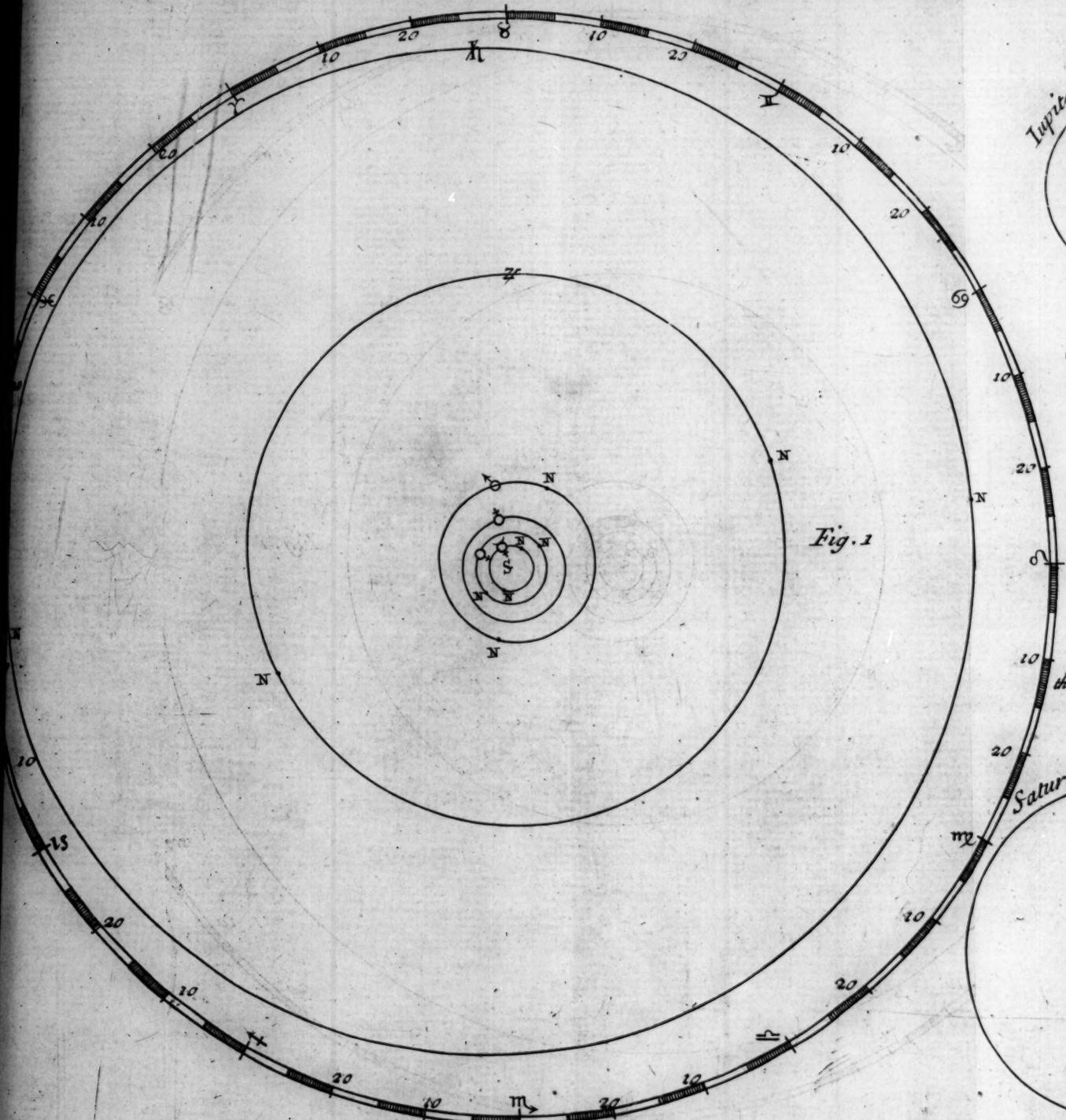


Fig. 1



Jupiter with his Satellites

Fig. 2

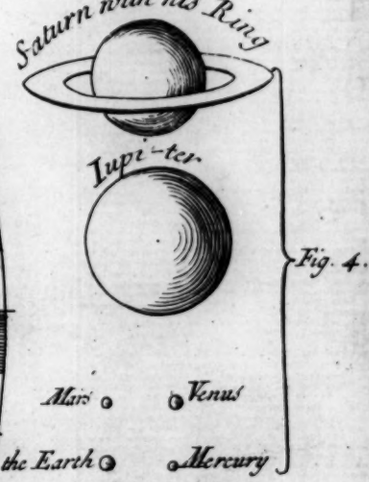
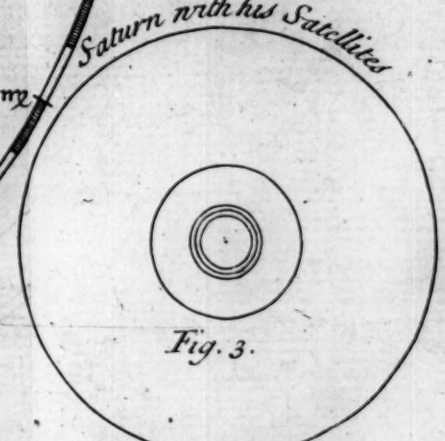


Fig. 4.



Saturn with his Satellites

Fig. 3.



The Moon moves about the Earth in an Ellipſe, 967
one of whoſe Foci is in the Center of the Earth, 968,
from which the mean Diſtance of the Moon is 60 969
Semidiameters of the Earth and a Half: *Its Eccentricity is liable to Change*; the mean one is of 3 Semidiameters and a Third. The Plane *of its Orbit* forms an Angle with the Plane of the Ecliptic of 5 Degr. *but this Inclination is not con-* 970
ſtant, or always the ſame. In the Motion of the Moon round the Earth, neither the Line of the Nodes, nor the Line of the Apſides, is carried in a parallel Motion; but the *Line of the Nodes* Weſtward, or in *Antecedentia*; *the Lines of the Apſides* Eaſtward, or in *Conſequentia*; the firſt performs its Revolution in about 9 Years, the ſecond in 19. The Periodical Time of the Moon's Motion about the Earth is 27 Days and about 7 Hours; and it is turned about its own Axis exactly in the ſame Time.

Plate XX. *Fig.* 2.] The firſt or inmoſt of the 971
Satellites of *Jupiter* is diſtant from *Jupiter*'s Center $2\frac{5}{6}$ Diameters of *Jupiter*: It is moved round *Jupiter* in one Day, 18 Hours, 28 Min.

The Diſtance of the Second is 4 and an Half Diameters of *Jupiter*: Its Periodical Time is 13 Hours, 18 Min.

The Diſtance of the Third is $7\frac{1}{6}$ Diameters; its Periodical Time 7 Days, 4 Hours.

The Fourth is diſtant $12\frac{2}{3}$ Diameters: It performs its Motion in 16 Days, 18 Hours, 5 Min.

Plate XX. *Fig.* 3.] The firſt or inmoſt Satel- 972
lite of *Saturn* is diſtant from *Saturn*'s Center $\frac{32}{40}$ of a Diameter of the Ring: Its Periodical Time is 1 Day, 21 Hours, 18 Min.

The Diſtance of the Second is $1\frac{1}{4}$ Diameter of the Ring: Its Periodical Time is 2 Days, 17 Hours, 41 Min.

The

The Diſtance of the Third is $1\frac{3}{4}$ Diameter of the Ring; its Periodical Motion is 4 Days, 13 Hours, 47 Min.

The Diſtance of the Fourth is 4 Diameters of the Ring; its Periodical Time 15 Days, 22 Hours, 41 Min.

The Diſtance of the Fifth is 12 Diameters of the Ring; its Periodical Time is 79 Days, 7 Hours, 53 Min.

973 Concerning the Motion of theſe, as alſo of the Satellites of *Jupiter* about their Axes, we can hitherto determine nothing certain from Aſtronomical Obſervations.

If we take Notice of the Diſtances and Periodical Times of the Planets, we ſhall find that the following Rule holds good in our Syſtem, wherever ſeveral Bodies are moved round the ſame Point, that is *about the* Sun, Saturn, *and* Jupiter;

974 (*viz.*) *The Squares of the Periodical Times are to one another, as the Cubes of the mean Diſtances from the Center.*

975 *Plate* XX. *Fig.* 4.] To give a Notion of the Dimenſions of the Bodies themſelves in our Syſtem, we have contrived the fourth Figure, in which all the Primary Planets, and *Saturn*'s Ring, are deſcribed, according to their Dimenſions; the Sun, whoſe Magnitude exceeds all the reſt, is repreſented by the greateſt Circle (*Fig.* 1.) that is, the Circle which terminates the Figure.

Theſe Dimenſions repreſent the Proportions of the Bodies one to another exactly enough, if you except the Earth, which, for the Reaſon already
955 mentioned, cannot be ſo compared with the other Bodies, as to leave no Room to doubt what Proportion it bears to them.

976 Yet *the Earth's Diameter may be meaſured,* and contains 3.400669 Perches, each of which is equal to 12 *Rhyniand* Feet; but altho' the Diameters of the other

other Planets may be compared together, and with the Sun's Diameter, yet it can't be determined how many Feet they contain, till after Obſervations ſhall be made at a proper Time hereafter.

Of the Bodies that make up the Planetary Syſtem, *the Moon only can be compared to the Earth*; its Diameter being to the Diameter of the Moon, as 40 to 11. 977

The other ſecondary Planets are not meaſured by Aſtronomers, but it can't be doubted, but that ſome of them are bigger than the Earth. 978

Beſides the Bodies already mentioned, there are others in the Planetary Syſtem, which are viſible for a Time, as they come near the Sun, and then recede from it, and become inviſible; they are called *Comets*. They *appear moſt commonly with Tails, and the Tail is always turned from the Sun*; *in their Motion they deſcribe Area's, by Lines drawn to the Center of the Sun, proportional to the Times*, as has been ſaid of the Planets.* 979 980 *944 966

As to Comets, it is probable that they move in elliptic Orbits, that are very eccentric; ſo that they are inviſible, when they are in that Part of the Orbit which is moſt diſtant from the Sun; which is deduced from the Periods of ſome of them, that have been obſerved to be pretty regular: And it is plain from Obſervations, that *ſome have deſcribed in their Motion Portions of very eccentric Eclipſes, in one of whoſe Foci was the Center of the Sun.* 981 982

The Notion, that we have hitherto given of the Planetary Syſtem, is founded upon Aſtronomical Obſervations; and what we have already ſaid admits of no Diſpute among Aſtronomers, if we except what relates to the Elliptic Line and the Motion of the Earth.

Some

Some affirm, that the Orbits of the Planets are not Elliptic, but that in their Motion they deſcribe another Oval: *Kepler* has deduced from *Tycho Brahé*'s Obſervations, that theſe Lines are Elliptic; and we ſhall ſhew in the following Part, that no other Curves can be deſcribed by the Planets.

Thoſe that ſay the Earth is at reſt, have no Aſtronomical or Phyſical Argument for a Foundation of their Opinion; that is, don't reaſon from *Phænomena*: Neglecting the Simplicity of the Syſtem, and the Analogy of the Motions, they aſſert, that their Opinion is not contrary to Obſervations; in which they err, as we ſhall ſhew in the following Part.

CHAP. II.

Concerning the Apparent Motion.

WHOEVER, after having read the former Chapter, looks upon the Heavens, will ſcarcely believe, that he beholds the Syſtem which is explained there; and a more exact Conſideration of the heavenly Motions will en-
983 creaſe his Doubt. No Wonder, *ſince we can obſerve very little in the Heavens but falſe Appearances.*

The common Obſerver of the Heavens is a Spectator, who, thinking himſelf to be at reſt, is carried about by various Motions, and beholds Bodies, concerning whoſe Diſtance and Magnitude he makes falſe Judgments. The true Syſtem of the World was unknown for many Ages, even to the moſt exact Obſervers of the Heavens.

But

But we muſt explain how all Things, which 984
are obſerved in the heavenly Bodies, have Place in the Syſtem that has been explained, in reſpect of a Spectator upon the Earth; that is, we ſhall deduce the Appearances from the true Motions. Which cannot be done, unleſs we firſt lay down ſome general Things concerning the apparent Motion in general.

It is certain, that we have no Art, by which we can diſcover the true Motion, only the relative Motion can be perceived by the Senſes; and it is that only concerning which we treated in the former Chapter. Who can reaſonably affirm or deny, that all the Bodies, which are known to us, are not carried in a common Motion through the immenſe Spaces?

The relative Motion to be diſtinguiſhed from the 985
apparent one; for the apparent Motion is the Change which appears to be in the Situation of the Bodies, and depends upon the Change of the Picture in the Bottom of the Eye; for Objects have the ſame apparent Relation to one another, as their Repreſentations have in the Eye; for they are ſeen as they are painted in the Eye; * *716
and the Change in that Picture, from the Motion of the Bodies, moſt commonly differs from the Change of the Relation between the Bodies themſelves; as follows from the Formation of that Picture.

The Heavens are nothing but an immenſe Space, 986
which cannot be ſeen, and would appear black, * *845
if innumerable Rays of Light, flowing from the heavenly Bodies, did not continually penetrate our Atmoſphere. Moſt of them come to us from the Bodies in right Lines, yet a great many ſuffer various Reflexions in the Atmoſphere, and enlighten the whole Atmoſphere; which is the Reaſon that, in the Day, Bodies are enlight-

ened, even without the Reflexion of the Clouds, to which the Rays of the Sun cannot come directly.

Theſe Rays are heterogeneous and white; for there are Bodies enlightened by theſe Rays which appear white: And theſe Bodies ſeen through Priſms, at the Extremities, are tinged with Colours, which does not happen in an homogeneous
*874 Colour; * alſo a Circle of white Paper of Half an Inch Diameter, being put upon black Cloth, if it is enlightened by theſe Rays, it will appear ob-
*861 long through the Priſm; * and the ſame Colours, which are obſerved in the Rays of the Sun, are ſeen here in the ſame Manner: All which Things would not happen, if the Air, as many think, was a blue Liquid; that is, through which only the Sun's blue Rays, at leaſt moſtly ſuch, paſs.

987 *When we look at the black Sky, the white Rays,* beforementioned, *enter our Eyes, whence the blue Colour of the Sky ariſes.* Becauſe we are accuſtomed to ſee a Colour where there is a coloured Object, we alſo refer the Colour of the Heavens to an Object; but ſince this is ſeen equally towards all
988 Parts, *we conceive a concave ſpherical Surface, in whoſe Center we are placed; we imagine this Surface to be opaque, and therefore diſtant from us beyond all viſible Bodies.*

When a Body is between a Plane and the Eye, of whoſe Diſtance we cannot judge, the Body appears to us to be applied to the Plane, whatſoever the Diſtance is between that and the Plane; for there is no Reaſon why the Parts of the Plane, which are painted at the Sides of the Image of the Body in the Eye, ſhould not appear at the ſame Diſtance with the Body.

989 Thence alſo *all the celeſtial Bodies* (of which the leaſt diſtant from us, (*viz.*) the Moon) is yet ſo removed that we can give no Judgment

of its Diſtance *, *are referred to that imaginary* *732
Sphere above-mentioned; and they all appear equally diſtant, and ſeem to move in the Surface of a concave Sphere. So the Moon appears to be amongſt the fixed Stars, although its Diſtance bears ſcarcely any ſenſible Proportion to the Diſtance of *Saturn*; and the Diſtance even of *Saturn* itſelf is nothing, compared with the immenſe Diſtance of the fixed Stars. It is no Wonder therefore, that the common People know nothing of the Magnitude of the celeſtial Bodies, and the Immenſity of the Heavens.

We ſee from what has been ſaid, how the Motion of any Body being given, and the Motion of the Earth being known, the apparent Motion may be determined.

We have ſaid that a Sphere is imagined beyond the fixed Stars, in whoſe Center is the Spectator: * The Orbit of the Earth is ſo ſmall, *988
in reſpect of the Diameter of this Sphere, that the Center of the Sphere is not ſenſibly changed by the Alteration of the Place of the Spectator, whilſt he is carried along with the Earth. Wherefore *in all the Points of the Earth's Surface, and at* 990
any Time, the Inhabitants of the Earth imagine the ſame Sphere, to which they refer the heavenly Bodies; and which hereafter we ſhall call *the Sphere of the fixed Stars.*

Theſe Things being laid down, *if we conceive* 991
a Line to be drawn through the Earth, and a Body, which, being continued beyond the Body, cuts the aforeſaid Sphere; we have a Point, to which the above-mentioned Body is referred, and *which is the apparent Place of that Body.*

Whilſt the Body, or the Earth, or both are moved, this Line is moved alſo, and *the apparent* 992
Motion is the Line, which is deſcribed amongſt the fixed Stars by the Extremity of the Line above-

mentioned, *which goes through the Earth and the Body, whoſe apparent Motion is obſerved.*

993 Therefore *the ſame Appearances will follow from the Earth's being moved out of its Place, as if the Body had been moved, and the ſame alſo may be deduced from the Motion of both.*

994 But *if the Body and the Earth be ſo moved, that the Line which paſſes through theſe Bodies be carried in a parallel Motion, the Body will ſeem to be at reſt amongſt the fixed Stars*; becauſe in this Caſe, the Space, gone through by the End of the Line amongſt the fixed Stars, cannot exceed the Space gone through by the Earth; but the Line that is equal to the whole Space which the Earth can go through, at ſo great a Diſtance as the fixed Stars, is not ſenſible to us.

995 *From the Motion of the Earth round its Axis* there *is* alſo *produced an apparent Motion*, which will be eaſily deduced in its proper Place from the Foundation laid down in this Chapter.

That the apparent Motion differs from the relative, and is varied by the Motion of the Spectator, is what Sailors every Day obſerve.

CHAP. III.

Of the Phænomena or Appearances of the Sun from the Motion of the Earth in its Orbit.

Plate XXI. *Fig.* 1.] LET the Sun be at S, and the Earth in its Orbit at T; and let *r s* be the Sphere of the fixed Stars; the *991 apparent Place of the Sun will be at *s*. * *When* 996 *the Earth is carried in its Orbit from* T to *t*, *the Sun ſeems to move in* Conſequentia, and to run *992 thro' the Arc *s r*,* which meaſures the Angle *r* S equal to the Angle T S *t*, ſo that the Celerity of the

the apparent Motion of the Sun depends upon the Celerity of the angular Motion of the Earth, with reſpect to the Center of the Sun; which Motion encreaſes upon a double Account; on account of the Diſtance from the Sun being leſſened, and the Celerity of the Earth being encreaſed: Both which Cauſes always concur; * * 944 *wherefore the Inequality of the apparent Motion of* 997 *the Sun is ſenſible. In a whole Revolution of the* 998, *Earth, the Sun alſo ſeems to run thro' a whole Circle.*

Definition I.

This apparent Way of the Sun is called the Eclip- 999 tic Line. It is the Section of the Sphere of the fixed Stars with the Plane of the Ecliptic, ſuppoſed to be continued to this Sphere.

This Way is divided into 12 equal Parts, each of which contains 30 Degr. Theſe Parts are called the Signs, and are diſtinguiſhed by theſe Names; *Aries* ♈, *Taurus* ♉, *Gemini* ♊, *Cancer* ♋, *Leo* ♌, *Virgo* ♍, *Libra* ♎, *Scorpius* ♏, *Sagittarius* ♐, *Capricorn* ♑, *Aquarius* ♒, *Piſces* ♓. Whence theſe Parts have their Names, we ſhall explain when we treat of the fixed Stars.

The Sun is longer a going thro' the ſix firſt Signs 1000 *than the ſix laſt, and the Difference is nine Days.*

Although a Circle has neither Beginning nor 1001 End, yet when ſeveral Points muſt be determined in it, ſome Point muſt be taken as *the Beginning*; this, *in the Ecliptic Line, is the firſt Point of* Aries; we ſhall ſhew how it may be determined hereafter. It is not fixed to one Place amongſt the fixed Stars; therefore *the Orbits of the* 1002 *Planets*, which alter ſo little, that they may be looked upon as unchangeable, * *don't preſerve the* * 929 *ſame Situation, in reſpect of this Point.*

Definition II.

1003 *The Diſtance of the Sun from the firſt Point of* Aries, *meaſured in* conſequentia, *is called* the Sun's Longitude.

1004 *The Longitudes of the other heavenly Bodies are meaſured after the ſame Manner in the Ecliptic;*

1005 *they are referred to this Line, by conceiving a great Circle to paſs through the Body, and cut the Ecliptic perpendicularly*; for the Point, in which the Ecliptic is cut by this Circle, determines the Longitude of the Body.

Definition III.

1006 *The Diſtance of a heavenly Body from the Ecliptic is called its* Latitude. It is meaſured by an Arc of a great Circle, perpendicular to the Ecliptic, intercepted between the Body and the Ecliptic.

Definition IV.

1007 *If we imagine a Line to go thro' the Center of the Sphere of the fixed Stars, and perpendicular to the Ecliptic, the Points, in which this cuts the abovementioned Sphere, are called the* Poles of the Ecliptic.

Definition V.

1008 *The* Zodiac *is a Zone which is imagined in the Heavens, which the Ecliptic Line cuts into two equal Parts, and which, on either Side, is terminated by a Circle parallel to the Ecliptic Line, and eight Degrees diſtant from it.* On Account of the ſmall Inclinations of the Orbits of the Planets, and the Moon to the Plane of the Ecliptic, no Bodies of

1009 the Planetary Syſtem appear without the *Zodiac*.

De

DEFINITION VI.

Thoſe of them that have the ſame Longitude are 1010
ſaid to be in Conjunction.

DEFINITION VII.

Thoſe whoſe Longitudes differ 180 *Degr. are ſaid* 1011
to be in Oppoſition.

CHAP. IV.

Of the Phænomena of the Inferior Planets, ariſing from the Earth's and their own Motions in their Orbits.

Plate XXI. *Fig.* 2.] LET S be the Sun, A V B *v* the Orbit of an inferior Planet; let T be the Earth in its Orbit, and *a* v *b* Part of the Sphere of the fixed Stars; the apparent Place of the Sun is v.* *991

If from the Earth there be drawn to the Orbit of the Planet the Tangents T A *a*, T B *b*, it is evident that the Planet, in its apparent Motion, is never removed farther from the Sun, than the Diſtance v *a*, v *b*; and that the Planet accompanies it in its apparent Motion round the Earth.

DEFINITION I.

The apparent Diſtance of the Planet from the 1012
Sun is called its Elongation; v *a* or v *b* is *the greateſt Elongation:* This varies upon two Ac- 1013
counts; (*viz.*) becauſe the Earth and the Planet revolve in elliptic Lines.* *929

The Planet performs its Motion ſooner than the 1014
Earth;* therefore, *in its Motion*, it *paſſes be-* *948
tween the Earth and the Sun, and then moves be-

yond the Sun, in reſpect of the Earth : So that it is in Conjunction with the Sun in two Manners, but *never in Oppoſition.*

That we may have an Idea of the apparent Motion of the Planet, we muſt conceive the Lines T B *b*, T S v, T A *a*, to move along with the Earth; ſo that the Points A, V, B, and *v*, whilſt the Earth performs its Revolution, may run thro' the Orbit of the Planet; but the Planet, which moves ſwifter, paſſes ſucceſſively through theſe Points over and over.

1015 *When* it is carried in its Orbit from V to D, it ſeems to move amongſt the fixed Stars from v to *d:* In this Caſe, *the apparent Motion is in* An-
1016 tecedentia, and *the Planet is retrograde.* In D it is ſaid to be *ſtationary*; becauſe *it appears, for ſome Time, in the ſame Place amongſt the fixed Stars :* This obtains, when the Orbit of the Planet, in the Place in which the Planet is, is ſo inclined to the Orbit of the Earth, in the Place in which the Earth is, that, if the Line *t d* be drawn parallel to the Line T D, and at a ſmall Diſtance from it, D *d* be to T *t* as the Celerity of the Planet in its Orbit, to the Celerity of the Earth; theſe
*53 Lines are run through in the ſame Time; * and the Line, which is drawn through the Earth and the Planet, is carried in a parallel Motion; for which Reaſon the apparent Place of the Planet is
*992 not changed. *

Between *d* and B, the Orbit of the Planet is more inclined to the Orbit of the Earth; wherefore the Extremity of the Line paſſing through the Earth and the Planet (although the Planet
1017 moves ſwifter than the Earth) is carried *in Conſequentia*; *towards which* Part alſo *the apparent Mo-*
*992 *tion of the Planet is directed.* * Yet ſince the apparent Motion of the Sun exceeds the apparent Motion of the Planet, the Elongation is increaſed, which becomes

becomes greateſt, when the Planet is at B. Whilſt the Planet goes through the Arc B *v*, its apparent Motion is alſo *in Conſequentia*, and exceeds the apparent Motion of the Sun to which it is coming, and then goes beyond it, receding from it, till it comes to A. Between A and E the Motion *in Conſequentia* is continued; but the Sun, whoſe apparent Motion in this Caſe is ſwifter, as has been explained concerning the Arc *d* B, comes towards the Planet, and the Elongation is diminiſhed. At E, in the ſame Manner 1018
as at D, *the Planet is* ſtationary, between E and V it is again retrograde.

The Orbit of the Planet is inclined to the Plane of *the* Ecliptic, ; * therefore it *does not* *958, 959
ſeem to move in the Ecliptic Line, but ſometimes leſs, ſometimes more diſtant from it, and *appears to be carried in an irregular Curve, which ſometimes cuts the Ecliptic.*

Plate XXI. *Fig.* 3.] Let N V N be the Orbit of the Planet, whoſe Nodes are N N; let S be the Sun; T *t* the Orbit of the Earth in the Plane of the Ecliptic; the Earth T; the Planet V. If V A be imagined to paſs through the Planet, and to be perpendicular to the Plane of the Ecliptick, the Angle V T A, or rather the Arc which meaſures it, is the Latitude of the Planet: * This is called *the Geocentric Latitude*, to *1006
diſtinguiſh it from the Latitude of the Planet ſeen from the Sun, which is called the *Heliocentric Latitude*, and is in that Caſe the Angle V S A. Here we ſpeak of the *Geocentric Latitude*, becauſe we examine the Phænomena as they appear from the Earth.

When a Planet appears in the Node, it appears 1019
in the Ecliptic Line; and the Curve, which is deſcribed by the Planet, by its apparent Motion in the Zodiac, cuts the Ecliptic Line; *as the Planet* 1120
recedes

recedes from the Node, its Latitude is encreaſed, which is alſo different, according to the Situation of the Earth; ſo the Planet remaining at V, the Latitude is greater if the Earth be at T, than if it was at *t*. Now, if the Earth remaining in its Place, we imagine the Planet to be carried from V to *v*, the Angle *v* T B will be leſs than the Angle V T A upon a double Account, from the Planet coming nearer the Node, and the Spectator being moved farther off.

Now, if we conſider that both the Earth and the Planet are continually moved, we ſhall eaſily conceive that the Latitude is changed every Moment from each Cauſe, which ſometimes act contrariwiſe, and ſometimes conſpire in encreaſing and diminiſhing the Latitude; whence it neceſſarily follows, that the Apparent Motion is performed in an irregular Curve, which, as was ſaid before, cuts the Ecliptic as often as the Planet paſſes the Node, that is, twice in each of its Revolutions: This Curve alſo does not recede from the Ecliptic, on either Side, beyond certain Limits in the Zodiac.

We diſcover alſo ſome remarkable Phænomena of the Inferior Planets by means of the Teleſcope, which are owing to their Opacity.

Plate XXI. *Fig.* 4.] Let S be the Sun, T the Earth, A, B, C, v, D, E, F, V, an inferior Planet, *ex. gr. Venus* in its Orbit. This Planet ſhines with Light borrowed from the Sun, and that Hemiſphere only which is turned to the Sun is enlightned, the other Hemiſphere is inviſible: Therefore that Part only of the enlightened Hemiſphere, which is turned to the Earth, can be ſeen from it; in V the Planet cannot be ſeen; in v it would appear round, if the Sun's Rays did not hinder it from being ſeen.

Going

Going from v *the Planet continually decreaſes*; 1021
at D it has the Figure *d*; at *e* and *f* it is drawn as it appears at E and F, and continues to decreaſe, *till it vaniſhes at* V, *and then again encreaſes ſucceſſively, changing its Figure*, 'till the whole enlightened Hemiſphere be turned towards Earth.

When the Node is at V, or near it, *the Planet* 1022
appears in the very Diſk of the Sun, and as it were applied to *it*, and *is obſerved as a black Spot which moves on the Sun's Surface*: In this Caſe, properly ſpeaking, we don't ſee the Planet, but we perceive where it intercepts the Sun's Rays.

The leſs diſtant the Planet is from the Earth, the 1023
greater it appears, * and the more lucid; but as it * 733
comes nearer the Earth, the lucid Part that is viſible is leſs; ſo that on one Account the Light encreaſes, and on another it is diminiſhed; *and there is a Diſtance at which the reflected Light is greateſt.*

CHAP. V.

Concerning the Phænomena of the Superior Planets, ariſing from their Motions and the Motion of the Earth in their reſpective Orbits.

THE Apparent Motions of the Superior Planets do in many Things agree with what has been explained in reſpect of the Inferior Planets, and in many Things diſagree. *They do not* 1024
always accompany the Sun, but are often obſerved in Oppoſition; but in their Oppoſition (as has been ſaid of the Inferior Planets) *they do not al-*
ways ſeem to be carried in Conſequentia, *but often* 1025
appear ſtationary, and often retrograde.

Plate

1026 *Plate* XXII. *Fig.* 1.] Let M be *a Superior Planet*, for Example, *Mars* in its Orbit, A T H B the Orbit of the Earth. The Periodical Time of the Earth is ſhorter than the Periodical Time
*948 of *Mars* *; therefore the Earth in its Motion goes between it and the Sun; in which Caſe the Planet *appears* at F, amongſt the fixed Stars *oppoſite to the Sun*. Through M draw the Lines B M, A M, that touch the Earth's Orbit, which, being continued, go to G and D in the Sphere of the fixed Stars. Let us imagine, that whilſt the Planet is carried about in its Orbit, thoſe Lines are alſo moved; ſo that the Points A and B, in which the Lines that go through the Planet touch the Orbit of the Earth, perform a Revolution in the Periodical Time of the Planet. Now ſince the Earth revolves faſter, it paſſes through the Points A and B in its Motion. In this Motion the apparent Place of the Planet, ſeen from the Earth, is not removed from the Place of the Planet ſeen from the Sun beyond F D and F G. Let T be ſuch a Point in the Orbit of the Earth, that the Line *t m*, being drawn, may be parallel to T M; let T *t* be to M *m*, as the Celerity of the Earth to the Celerity of the Planet; in which Caſe theſe ſmall Lines are gone through
*53 in the ſame Time; * in the mean time the Planet
*994 ſeems to be at reſt, * and is ſaid to be ſtationary. In the ſame Manner it is ſtationary when the Earth is at H. In the Motion of the Earth between T and H, the Planet appears to move in *Antecedentia* from E through F, and is ſaid to be retrograde; whilſt the Earth goes through the reſt of its Orbit, the Planet is direct.

1027 The Phænomena, which relate to the Latitude, are like thoſe which have been explained, in re-
*1008 ſpect to the inferior Planets. *

Jupiter

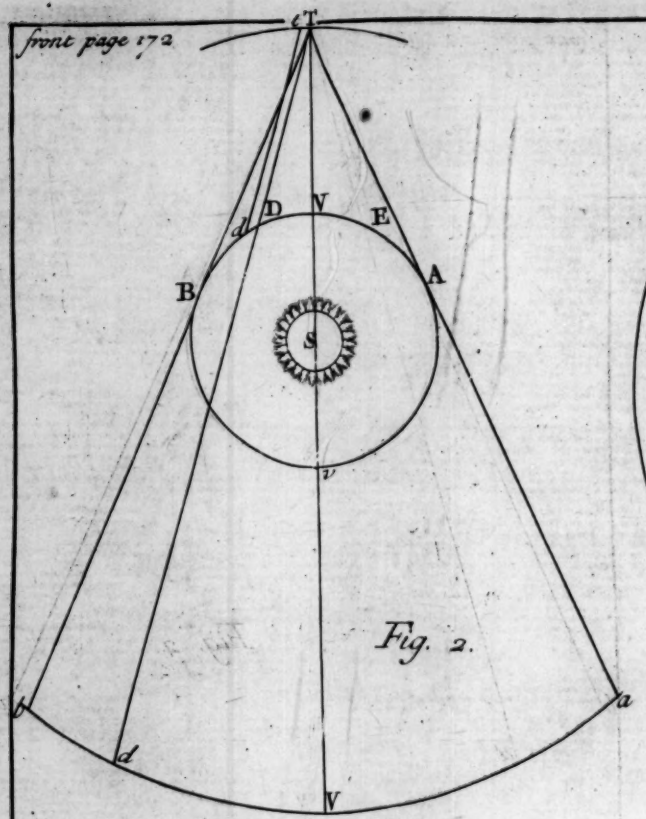


Fig. 2.

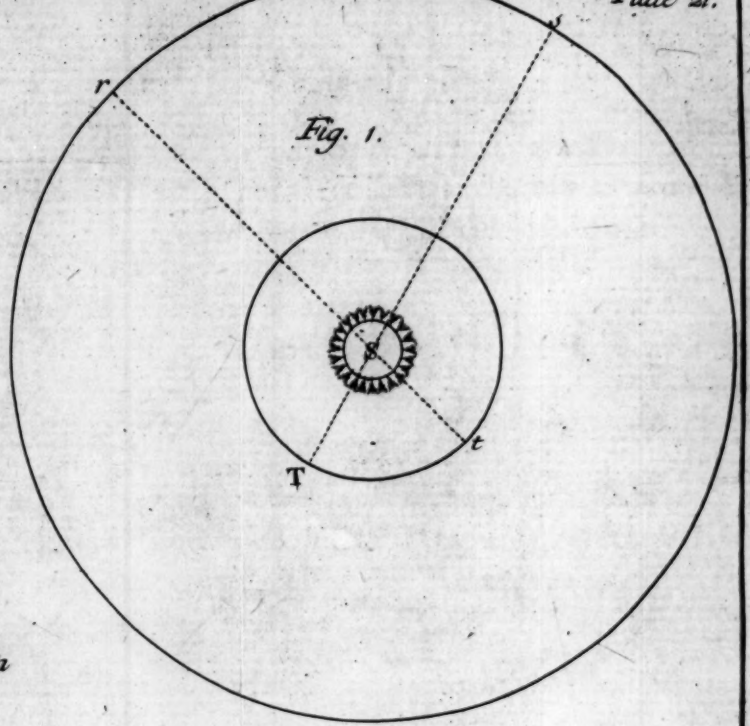


Fig. 1.

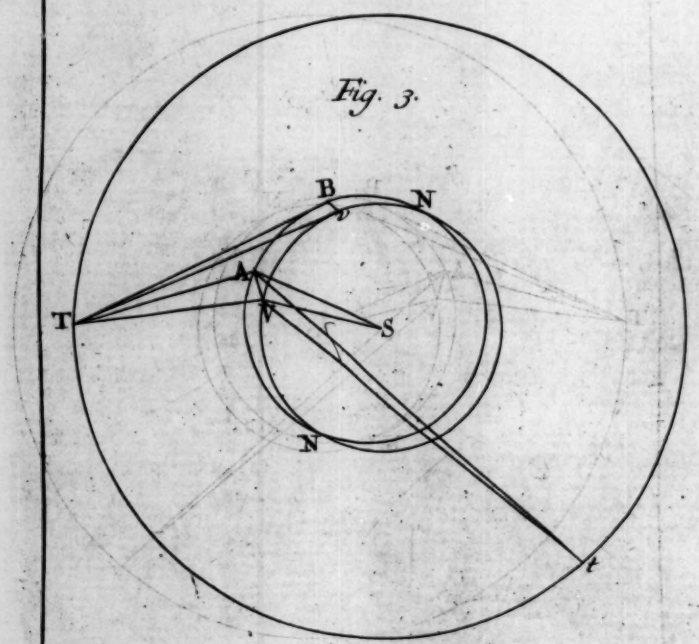


Fig. 3.

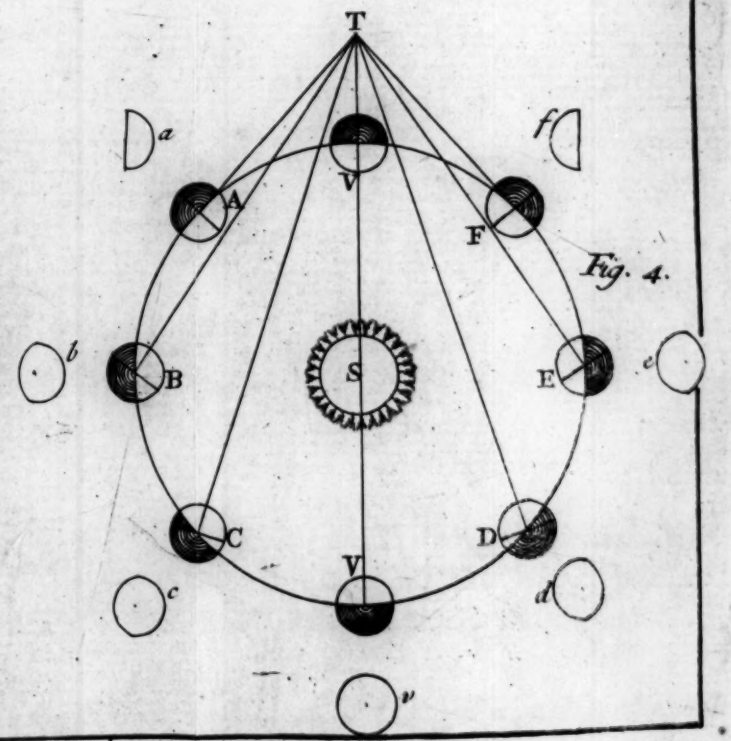


Fig. 4.



Jupiter and *Saturn* encompaſs the Orbit of the Earth at a great Diſtance; wherefore almoſt their whole Hemiſpheres, which are enlightened by the Sun, are viſible from the Earth; and therefore theſe Planets *always appear round.* 1028

Becauſe *Mars* is leſs diſtant, it *appears a little gibbous, between the Conjunction and Oppoſition with the Sun.* 1029

CHAP. VI.

Concerning the Phænomena of the Satellites, from their Motion in their Orbits. Where we ſhall ſpeak of the Eclipſes of the Sun and Moon.

THE *Satellites of* Jupiter *and* Saturn *do always accompany their Primaries in their Motion, and never appear to recede from them beyond certain Limits on either Side,* which may be eaſily determined from their Diſtances from their Primaries; *and they are alternately carried* in *Antecedentia* and in *Conſequentia.* Sometimes all of them are on the ſame Side of the primary Planet, and ſometimes the Primary is obſerved to be between them; *they are* all *always in the ſame Right Line, or very little diſtant from it.* All which Things may be deduced from this, That the Motion about the primary Planets is performed in Planets that make ſmall Angles with one another, and with the Plane of the Ecliptic. 1030 1031

All *the Satellites of* Saturn *or* Jupiter are not always viſible at the ſame Time; *ſometimes* they *are hid by their Primary,* and *often immers'd in its Shadow.* 1032

DEFINITION I.

Plate XXII. *Fig.* 2.] Such an Immerſion in the Shadow is called an *Eclipſe of the Satellite.* 1033

Let

Let S be the Sun, T *t* the Orbit of the Earth, I *Jupiter*, M *m* the Orbit of a Secondary of *Jupiter*. Whilſt the Secondary moves from M to *m*, it undergoes an Eclipſe; and, not being enlightened by the Sun, becomes inviſible. If the Earth be at T, the Emerſion into the Shadow is eaſily obſerved; on the contrary, the Emerſion is more ſenſible, if the Earth be placed at *t*.

1034 Amongſt the Bodies that accompany *Saturn*, *963 we have ſaid that there is *a Ring*; * concerning which it is to be obſerved, *that an Obſerver upon the Earth never ſees it wider than it is repreſented in the* 4*th* Fig. *of Plate* XX. *and that ſometimes it is inviſible*; namely, when the Plane of the Ring being continued, goes through the Earth; for the Thickneſs of the Ring is not ſenſible. The Ring is alſo inviſible, when its Plane continued paſſes between the Earth and the Sun; for then the enlightened Surface of the Ring is turned from the Earth: In each Caſe *Saturn* appears round, yet in the laſt Caſe, by reaſon of the Rays that are intercepted by the Ring, there appears a black Belt upon the Surface of the Planet, like that which is occaſioned by the Shadow of the Ring.

The Phænomena of the Earth's Satellite, namely of the Moon, are very remarkable in reſpect to us, and therefore particularly to be explained.

1035 It is very often in Conjunction with the Sun, and as often in Oppoſition to it, but not at every Revolution of the Moon in its Orbit; for whilſt the Moon, after one entire Revolution of 27 Days and 7 Hours, returns again to the Place 1036 amongſt the fixed Stars, in which it was in Con- *960 junction with the Sun, the Sun is gone from that 996 Place, and is about 27 Degr. diſtant from it: * 998 there-

therefore *the neighbouring Conjunctions are twenty-nine Days and a Half diſtant from one another.*

Definition II.

The Lunar Periodical Month *is the Time of one* 1037
Revolution of the Moon in its Orbit.

Definition III.

The Moon's Synodical Month, or a Lunation, 1038
is the Time that the Moon ſpends between the two next Conjunctions with the Sun.

The Moon is inviſible in its Conjunction with the 1039
Sun, becauſe the enlightened Hemiſphere is turned from the Earth. Let T (*Plate* XXII. *Fig.* 3.) be the Earth, N the Moon between the Sun and the Earth, the enlightened Hemiſphere will be *m l*, which cannot be ſeen from the Earth.

Whilſt the Moon is carried, in its Orbit, *from the* 1040
Conjunction to the Oppoſition, the enlightened Part, which is directed towards the Sun, *does continually become more and more viſible to the Inhabitants of the Earth*; and in the Points A, B, C, the Moon does ſucceſſively acquire the Figures *a*, *b*, *c*.

At P, *in* its *Oppoſition with the Sun*, *it appears* 1041
round; *then going through* D, E, F, *it decreaſes*, as it is repreſented at *d*, *e*, *f*.

Definition IV.

The Conjunction of the Moon with the Sun is 1042
called the New-Moon.

After the Conjunction, the Moon is as it were renewed.

Definition V.

The Oppoſition of the Moon with the Sun is called 1043
the Full-Moon, *becauſe the whole Moon appears enlightened.*

De-

Definition VI.

1044 *The Conjunction and Oppoſition of a Satellite with the Sun, are called by the common Name* Syzygies.

1045 At A and F, the dark Part of the Moon is a little enlightened by the Rays that are reflected from the Earth; and therefore it is ſeen by a Spectator to whom the Sun is not viſible, that is, in the firſt Caſe, after the Setting of the Sun, and in the ſecond, before its Riſe.

Definition VII.

1046 *When the Light of the Sun is intercepted by the Moon, ſo that, in reſpect of any Obſerver upon the Earth, the Sun is partly or wholly covered, the Sun is ſaid to undergo an* Eclipſe.

Properly ſpeaking, this is an Eclipſe of the Earth, on whoſe Surface the Shadow or *Penumbra* of the Moon falls.

Definition VIII.

1047 An Eclipſe of the Moon *is the Obſcuration of the Moon by the Shadow of the Earth.*

1048 *The Eclipſe of the Sun is never obſerved, except at the Time of the New-Moon.*

1049 *The Moon is never eclipſed but at the Time of the Full-Moon.*

1050 Yet the Luminaries are not eclipſed at every one of the Syzygies, becauſe the Moon does not move *969 in the Plane of the Ecliptic, * in which the Sun and Earth always are; wherefore, upon Account of the Moon's Latitude, its Shadow, at the New-Moon, often does not touch the Earth; and itſelf, at the Full-Moon, paſſes beſide the Shadow of the Earth.

1051 But *when the Moon* has no Latitude, or but very little, that is, when it *is in the Node, or near it, at its Syzygies, an Eclipſe is obſerved*; in that

Plate

Caſe the Moon appears to be in the Ecliptic, or very near it; and this it is that has given the Name to that Line.

Plate XXIII. *Fig.* 1.] That what relates to the Eclipſe of the Moon may appear the more plainly, let O O be the Way of the Moon, R R the Plane of the Ecliptic; the Center of the *904, Earth's Shadow is always in it; *N is the Node 939 of the Moon's Orbit.

If the Center of the Earth's Shadow be at A, the Moon that goes by at F will not be darkened.

If the Moon be leſs diſtant from the Node at 1052 the Full-Moon, as at G, the Shadow of the Earth is at B, and *the Moon is darkened in part; this is called a partial Eclipſe.*

If, ſuppoſing the Shadow at D, the Moon be 1053 Full, *the Moon* will *be wholly darkned* at I, it runs into the Shadow at L, and goes out of it at H; and *the Eclipſe is ſaid to be Total.*

The Eclipſe is ſaid to be Central, when the Cen- 1054 *ter of the Moon goes through the Center of the Shadow, which only happens in the very Node* N.

We have hitherto ſpoken of the Shadow of the Earth; becauſe, when we mention the Earth, we underſtand its Atmoſphere which is joined to it, of which we have ſpoken elſewhere: **The Shadow* *418 *of the Atmoſphere is* properly *conſidered in Lunar* 1055 *Eclipſes*; for the Shadow of the Earth itſelf does not reach the Moon.

Plate XXIV. *Fig.* 1.] Let T be the Earth, the Atmoſphere about it F D G G D F. The Sun's Rays B D, B D, touching the Atmoſphere; theſe go ſtreight on, and terminate the Shadow of the Atmoſphere, out of which if the Moon be, it is immediately enlightened by the Sun's Rays, but it is not enlightened in the ſame Manner all the while it is between B D and B D.

1056 *The Rays which enter the Atmoſphere obliquely* are
*617 refracted; * and, as they come towards the Earth,
they continually penetrate into a Medium which
*424 is denſer and denſer, * and therefore are every
429 Moment inflected and *move into Curves*. So the
*617 Rays E F, E F, penetrate the Atmoſphere in the Curves F G, F G, that touch the Earth. All the Light between E F, E F, is intercepted by the Earth, and the Rays G A, G A, terminate the Earth's Shadow.

The Light between E F and B D, being refracted by the Atmoſphere, is ſcattered between G A and B D continued, and beyond A, the Point of the Earth's Shadow, the Lights that
1057 come from all Parts are confounded, but are continually weaker and weaker the farther from the Earth: So that *the Shadow of the Atmoſphere is* not a perfect Shadow, but *a weak Light*, whereby the Moon is viſible in an Eclipſe.

1058 *The Shadow of the Atmoſphere* is Conical, becauſe the Sun's Diameter is greater than the Diameter of the Atmoſphere, which is ſcarce bigger than that of the Earth; and this Cone *does not reach quite to Mars*, as appears from immediate Obſervations; but the Shadow of the Diameter, in the Place where it is cut by the Moon's Orbit, is ſcarce one Fourth leſs than the Diameter of the Earth.

With the ſame Reaſoning that we have proved, that the Moon comes into the Shadow of the Atmoſphere, when the Moon in its full is in the Node or near it; it is alſo proved, that the Moon's Shadow falls upon the Earth *at the New-Moon, when the Moon is in the Node or near the Node*;
1059 therefore in that Caſe *the Sun undergoes an Eclipſe*; concerning which, ſeveral Things are to be obſerved.

Plate XXII. *Fig.* 4.] Let S be the Sun, T the Moon; let the Shadow of it fall upon any Plane G H. This Shadow is encompaſſed with a Penumbra, for beyond L and E that Plane is enlightened by one entire Hemiſphere of the Sun; as you go from L to H, and from E to G, the Light is continually diminiſhed, and near G and H the Rays come to the Plane only from a ſmall Part of the Sun's Surface.

Definition IX.

This diminiſhed Light, which encompaſſes the 1060
Shadow G H *every Way, is called* the Penumbra.

In the Eclipſe of the Moon, the Shadow of the 1061
Earth is encompaſſed with *the like Penumbra,* but this is only ſenſible near the Shadow, and therefore *has but a ſmall Breadth; but* if *an Obſerver* be placed upon a Plane upon which the Shadow falls, he *may obſerve the whole Penumbra;* as is 1062
the Caſe *in the Eclipſe of the Sun.* An Obſerver I or F can only ſee the Semidiameter of the Sun, the reſt of the Diameter is hid by the Moon; and going from L towards H, the Sun is continually more and more hid by the Moon, till it becomes wholly inviſible in the Shadow itſelf.

Hence it follows, that *there is a Solar Eclipſe,* 1063
though the Shadow of the Moon does not touch the Earth, provided the Penumbra comes to its Surface.
And alſo, *that the Eclipſe is not obſerved in all the* 1064
Places in which the Sun is viſible; and that it is 1065
different, according as the Shadow or a different Part of the Penumbra goes through the Place, *in the Places in which it is obſerved.*

But the Eclipſe of the Moon is every where the 1066
ſame, where the Moon is viſible, during the Eclipſe.

But when the Shadow itſelf of the Moon falls upon 1067
the Earth, the Sun's Eclipſe is ſaid to be Total; if only the Penumbra reaches the Earth, it is ſaid to be

Partial; and this is what happens when we conſider an Eclipſe in general.

1068 But, as to particular Places, *it is ſaid to be Total in thoſe Places where the Shadow paſſes*; *Central, in thoſe* where the Center of the Shadow paſſes, that is, *where the Center of the Moon covers the Sun's Center*; and laſtly, *Partial, where the Penumbra only goes by*; and this is drawn in *Fig.* 6.

1069 *Plate* XXII. *Fig.* 4.] *The wider the Shadow* GH *is, the more Places is the Eclipſe of the Sun Total in, and the longer is the Sun wholly obſcured.* But the Breadth of the Shadow is different according to the differenr Diſtances of the Moon from the Earth, and of the Earth from the Sun.

1070 *If there be an Eclipſe of the Moon, ſuppoſing the Earth in the Peribelion*, and *the Moon in the Apogæum*, that is, at the greateſt Diſtance from the Earth, the Shadow of the Moon does not reach the Earth, and *the Moon does not cover the whole Sun*; *ſuch an one is* called *an Annular Eclipſe*, and is repreſented in *Fig.* 5.

CHAP. VII.

Of the Phænomena ariſing from the Motion of the Sun, the Planets, and the Moon, about their Axes.

1071 THE *Sun's Motion about its Axis is ſenſible, by obſerving the Spots*, which are obſerved very often upon the Sun's Surface. Theſe Spots ſeem to change their Figure and Situation every Day, and ſometimes to move ſwifter, ſometimes ſlower; all which Things may be eaſily deduced from the Motion of a Spherical Surface; and the Sun, which, if it was not moved by ſuch a Motion, would only once in a Year ſucceſſively turn

urn its whole Surface to the Earth, now ſhews it to the Inhabitants of the Earth in leſs than the Space of one Month.

Such like Phænomena ariſe from *the Rotation of* 1072
Jupiter, Mars, and Venus, about their Axis, which Motions *become ſenſible, by obſerving the Spots in the Surface of the Planets.*

Whilſt the Earth is moved round its Axis, the Obſerver, who is carried round, imagines himſelf to be at reſt, and all the heavenly Bodies to be in Motion.

Definition I.

The Points, in which the Axis of the Earth, be- 1073
ing continued both Ways, touches the Sphere of the fixed Stars, are called the Poles of the World.

Definition II.

The apparent Motion, ariſing from the Motion of 1074
the Earth about its Axis, is called The Diurnal Motion.

Definition III.

A Plane is conceived to paſs through the Center 1075
of the Earth, perpendicular to its Axis, and continued every Way, and the Circle, in which it cuts the Sphere of the fixed Stars, is called The Cœleſtial Æquator.

In the Motion of the Earth round the Sun, the 1076
Æquator is moved; but ſince the Plane of this Circle is carried by a parallel Motion, *the Cœleſtial Æquator is not moved.** *994

Definition IV.

Circles, whoſe Planes go through the Axis of the 1077
Earth, are called Meridians.

They all paſs through the Poles of the World, and 1078
are perpendicular to the Æquator.

Definition V.

1079 *The Arc of any Meridian, which is intercepted between the Æquator and a Star, is called* the Declination of that Star.

Plate XXIII. *Fig.* 2.] Let an Obſerver be upon the Earth T, who directs his Sight along T A; after a little Time, when the Line T A ſhall be be carried by the Motion of the Earth to T *a*, if the Spectator directs his Sight through the ſame Line, the Body A will appear to have been carried through the Arc *a* A; but when the Line has returned to its former Situation T A, the Body will ſeem to have performed one whole Revolution. But if he directs his Sight along the Axis of the Earth produced, becauſe that is at reſt, the Body, which is ſeen in the Axis, will appear not to
1080 have moved; therefore *in the Poles of the World the*
*1073 *diurnal Motion is not obſerved.* * But that Bodies, which are near the Poles, are moved round them is plain; and that the Body by its diurnal Motion deſcribes ſo much a greater Circle round the immoveable Pole, as it is farther diſtant from it.
1081 Therefore *the whole Sphere of the fixed Stars ſeems to revolve about the Axis of the Earth continued,* in Antecedentia, *in that Time in which the Earth really turns about its Axis.* Therefore the diurnal Motion is common to all the cœleſtial Bodies, except ſo far as it is diſturbed by the Motions above-mentioned.

The Æquator is equally diſtant from both Poles, and divides the Heavens into two Hemiſpheres, whoſe middle Points are the Poles, which therefore are equally diſtant from the ſeveral
1082 Points of the Æquator; therefore *the heavenly Bodies which are in the Æquator by their diurnal Motion ſeem to deſcribe the Æquator itſelf,* the greateſt Circle of all that can be deſcribed by

by the diurnal Motion; *the other Bodies deſcribe* 1083
Circles parallel to the Æquator.

The Axis of the Earth is inclined to the Plane of the Ecliptic in an Angle of 66 Degr. 31 Min. * *960
The Poles of the World therefore *are diſtant from* 1084
the Poles of the Ecliptic 23 Degr. 29 Min. *and the Plane of the Æquator makes an Angle with the Plane of the Ecliptic of* 23 Degr. 29 Min. Both Planes paſs through the Center of the Earth; but ſince this may be looked upon as the Center of the fixed Stars, * it follows, that *the Æquator and* 1085
the Ecliptic Line are great Circles, which are inclined *988
to each other, and *cut one another in two oppoſite* 990
Points, in the Beginning of Aries, *and the Beginning of* Libra; which Points, in the Way of the Sun, are determined by theſe Interſections. * *1001

When the Sun is in thoſe Points, it ſeems to de- 1086
ſcribe the Æquator by its diurnal Motion; * *when it* 1087
is carried about *in the Ecliptic* by its apparent Mo- *1082
tion, it continually recedes more and more from the Æquator, and its Declination is increaſed, *and* it *deſcribes leſs Circles every Day;* * *till it comes to* *1083
its greateſt Diſtance from the Equator, which is 23 1088
Degr. 29 Min. * *then it comes back to the Æquator* *1084
again, and goes beyond it alſo 23 Degr. 29 Min. *advancing towards the oppoſite Pole.*

Definition VI.

Thoſe Circles, deſcribed by the Sun in its diurnal 1089
Motion, which are moſt diſtant from the Æquator, that is, 23 Degr. 19 Min. *are called* the Tropics.

One touches the Ecliptic Line in the firſt Degree of *Cancer*, and is called the Tropic of *Cancer*; the other is called the Tropic of *Capricorn*, and paſſes through the firſt Point of the Sign *Capricorn*, and there touches the Ecliptic Line.

Definition VII.

1090 *The Pole of the World, which is next to the Tropic of* Cancer, *is called the* Arctic Pole, *and alſo the* North Pole; *the Oppoſite is called* the Antarctic, *and alſo* the South Pole.

Definition VIII.

1091 *The Circles* that are deſcribed in the diurnal Motion by the Poles of the Ecliptic, that is, by the Points *which are diſtant from the Poles of the World* 23 Degr. 29 Min. *are called* the Polar Circles.

The Arctic Polar Circle is that which ſurrounds the Arctic Pole; the other oppoſite one borrows its Name from the Antarctic Pole.

1092 There remains to be explained *the Moon's Motion about its Axis, whoſe Effect is, that the ſame Face of the Moon is always turned towards the Earth.*

Plate XXII. *Fig.* 3.] Let the Moon be at N, the Face which is turned to the Earth is *m n i*; if the Moon did not turn about its Axis, and all its Points were carried through parallel Lines, the Line *m i* would coincide with the Line *l n* in the Situation of the Moon at B, and the aforeſaid Hemiſphere *m n i*, would be at *l m n*; but becauſe, whilſt the Moon deſcribes a fourth Part of its Orbit, it performs likewiſe $\frac{1}{4}$ of its Revolution round its Axis, the Face, which would be at *l m n*, is now at *m n i*, that is, again turned to the Earth. After the ſame Manner it is proved, that this ſame Face *m n i*, when the Moon is at P, is ſeen by an Obſerver on the Earth, and that it is turned towards the Earth at E; as alſo in all other Points of the Moon's Orbit.

1093 *The Axis of the Moon* is not perpendicular *to the Plane of its Orbit*, but *a little inclined* to it: The Axis keeps its Parallelism in its Motion round the Earth, as has been ſaid of the Primary

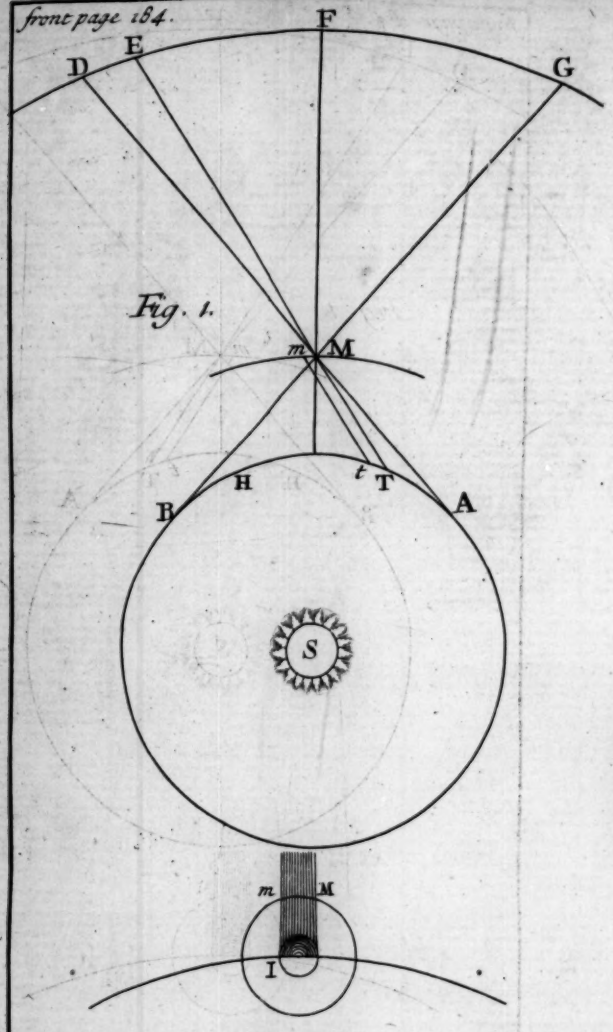
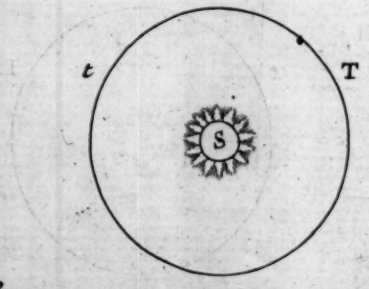


Fig. 1.

Fig. 2.



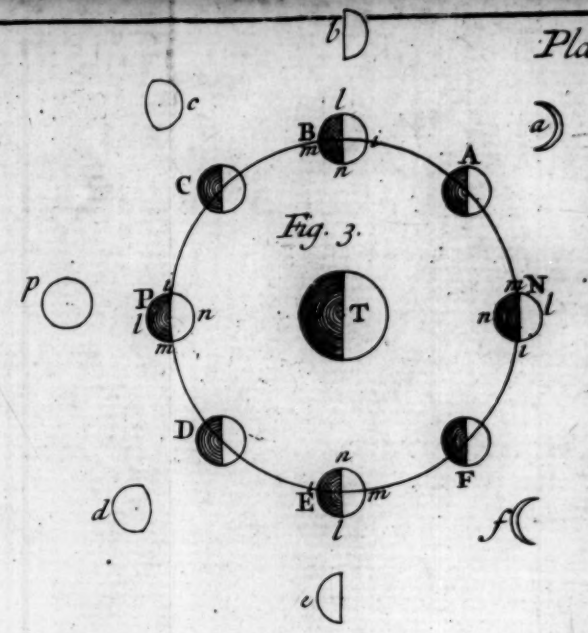


Fig. 3.

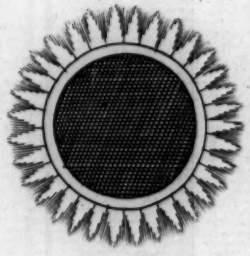


Fig. 5.

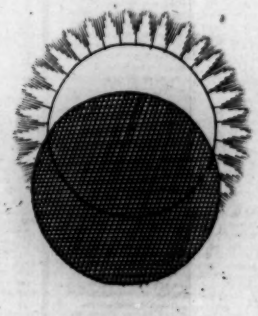


Fig. 6.

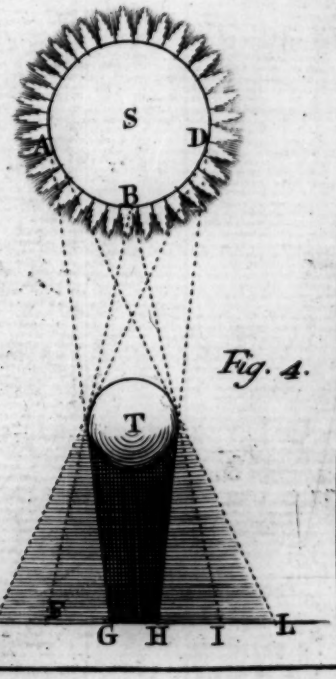
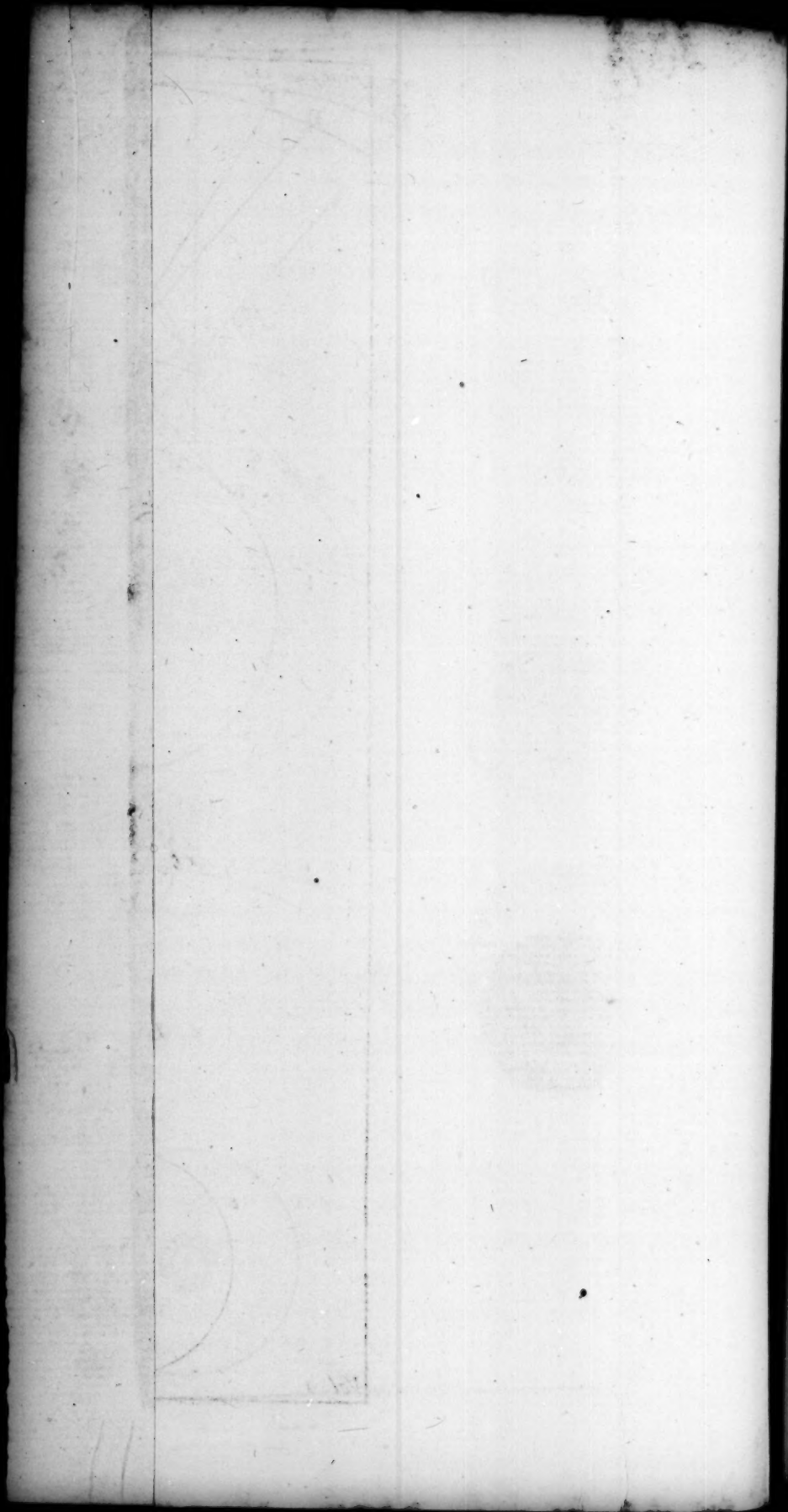


Fig. 4.



mary Planets; * therefore it changes its Situation, *952
in reſpect of an Obſerver upon the Earth, to whom ſometimes one, ſometimes the other Pole of the Moon is viſible, whence *it ſeems to be agitated by a* Sort *of libratory Motion.* There is an- 1094
other libratory Motion obſerved in the Moon; the Motion about the Axis is equable, and it is carried in its Orbit with an unequal Celerity; * therefore *966
when the Moon is at its *Perigæum*, that is, at its leaſt Diſtance from the Earth where it is moved the ſwifteſt in its Orbit,* that Part of its Surface, *966
which, on Account of its Motion in the Orbit, would be turned towards the Earth, is not wholly turned from it on Account of its Motion round its Axis: Therefore ſome of that Part of the Surface of the Moon, which before was not viſible, is ſeen at the Side; which, when the Moon is at its *Apogæum*, is again viſible.

CHAP. V.

Of the Phænomena which relate to the Surface of the Earth, and its particular Parts.

WE have explained the Cœleſtial Phænomena hitherto examined, by conſidering the Spectator as carried about by thoſe Motions wherewith the Earth is really moved. Now we ſhall conſider him as placed upon the Surface of the Earth, and carried from one Place to another upon it.

The firſt Phænomena to be here obſerved is, 1095
that, *by reaſon of the Interpoſition of the Earth, one Half of the Heavens is inviſible to the Obſerver who is placed upon the Surface of the Earth.*

DEFINITION I.

That Circle in the Heavens, which ſeparates the vi- 1096
ſible from the inviſible Part, when the Rays are not

not intercepted by the Inequalities of the Earth's Surface, *is called the* Horizon.

When the Height, to which the Spectator can be raiſed above the Surface of the Earth, is very ſmall, compared with the Semidiameter of the Earth; the Eye of the Spectator may be looked upon as placed in the Surface itſelf.

Plate XXIII. *Fig.* 4.] Let the Earth be at T, and the Obſerver at S, and P E *p e* the Sphere of the fixed Stars; if you conceive a Plane at H H to touch the Earth and go through S, it will be the Plane of the Horizon, whoſe Section with the Sphere of the fixed Stars is the Horizon. A Plane, as *h h*, is conceived to go through the Center of the Earth, parallel to H H; the Diſtance *h* H is inſenſible, by reaſon of the immenſe Diſtance of the fixed Stars; therefore the Section of that Plane, with the Sphere above-mentioned, may be taken
994 for the Horizon.

DEFINITION XII.

8097 *The Aſcent of the* Stars, *above the Horizon, is called their* Riſe.

DEFINITION III.

1098 *The Deſcent, below the Horizon, is called the* Setting *of the Stars.*

DEFINITION IV.

1099 *If we conceive a Line drawn through the Obſerver and the Center of the Earth,* which muſt neceſſarily be perpendicular to the Horizon, *it will reach the Point* Z *among the fixed Stars, which is called the* Zenith.

DEFINITION V.

1100 *The Point* N, *oppoſite to it, is called the* Nadir.

DEFINITION VI.

1101 *The Section which a Plane of the Meridian, that goes through the Obſerver, makes with the Horizon, is called the* Meridian Line; and is directed from North to South.

DEFI-

Definition VII.

The Eaſtern Part of the Heavens *is that, from* 1102
which we ſee the Bodies riſe above the Horizon; and the Eaſt Point *is that, in which a Line directed Eaſtwards, perpendicular to the Meridian Line, and going thro' the Obſerver, cuts the Sphere of the fixed Stars.*

Definition VIII.

The Point, oppoſite to this, is called the Weſt 1103
Point; *and the* Weſtern Point of the Heavens *is oppoſite to the Eaſtern Part.*

Definition IX.

The Amplitude *is an Arc of the Horizon, which* 1104
is contained between the Eaſt or Weſt Point, and the Point in which the Star riſes or ſets. The firſt is called the Riſing, and the other the ſetting Amplitude: And each is either Northern or Southern Amplitude.

Definition X.

The Height or Altitude of a Star, above the 1105
Horizon, *is the Arc of a Circle perpendicular to the Horizon, in whoſe Center the Spectator is, terminated by the Horizon and the Star.*

Definition XI.

The Difference of the Height of a Star, according 1106
to the different Poſition of the Obſerver, as he is ſuppoſed in the Center, or on the Surface of the Earth, is called the Parallax of the Star.

There is only the Parallax of the Moon, which can 1107
be determined by Obſervations: The Diſtance of the reſt of the Bodies in the Planetary Syſtem is too great to be compared with the Semidiameter of the Earth; and the Parallax depends upon the Ratio which the Semidiameter of the Earth has

to

to the Diſtance of a Planet; therefore even *the*
1108 *Parallax of* Mars, *in Oppoſition with the Sun, is too ſmall for the niceſt Obſervations.*

1109 Where there is a *Parallax*, it *diminiſhes as a Body aſcends above the Horizon, and vaniſhes in the Zenith.*

The apparent Height of the Stars is alſo changed upon another Account, which equally affects all the
1110 heavenly Bodies. The Rays are inflected *by the*
1111 *Refraction of the Atmoſphere*,* and *the Stars ap-*
*1056 *pear higher than they are*;* *yet the higher they*
*624 *are, the leſs is that Inflexion*;* becauſe the Rays
*639 fall leſs obliquely on the Surface of the Atmoſphere.
1112 *In the* Zenith *there is no Refraction**; *even at the*
*629 *Diſtance of twenty or thirty Degrees from the* Zenith, *it is not ſenſible.*

1113 Since *the Stars* are raiſed *by this Refraction*, they *are viſible before they come to the Horizon.*

Plate XXIV. *Fig.* 2.] All theſe Things relate to the Surface of the Earth in general, now we muſt examine the ſeveral Parts of it; theſe are determined, by referring to the Earth the ſeveral Circles which we have before conſidered in the
1114 Heavens; ſo *on the Earth we conſider the Æquaton, the Meridians, the Tropics, and Polar Circles*; and theſe Circles divide the Surface of the Earth in the ſame Manner as the Sphere of the fixed Stars is divided by the Circles in the Heavens: And therefore the Circles in the Heavens, and thoſe upon the Earth, do ſo mutually correſpond with each other, that a Line being drawn from the Center of the Earth to a Circle in the Heavens, it will go through the ſame Circle in the Earth. If the Poles are P, *p*, the Æquator will be E *e*, the Tropics T T, *t t*, and the Polar Circles A A, *a a*.

Definition XII.

1115 *The Meridian, which goes through a Place, is called the* Meridian of the Place. *The*

The Plane of it is perpendicular to the Horizon; 1116
becauſe it goes through the Center of the Earth, and the Obſerver.

A Meridian Line, drawn in any Place, is Part 1117
*of the Meridian of the Place.** *1101

Definition XIII.

The Latitude of a Place *is its Diſtance from* 1118
the Æquator; that is, the Arc intercepted between that Place and the Æquator.

Definition XIV.

Circles, parallel to the Æquator, are called Cir- 1119
cles of Latitude.

By determining the Latitude of the Place, we determine the Circle of Latitude, which goes through the Place; now, to determine the Situation of ſeveral Places, in reſpect of each other, we muſt determine Places upon the ſeveral Circles; which is done, by ſuppoſing a Meridian to paſs through any remarkable Place, which, by its Section, determines a Point upon each Circle of Latitude, from which the Diſtances of Places are meaſured.

Definition XV.

The Meridian above-mentioned, taken at Plea- 1120
ſure, is called the Firſt Meridian.

Definition VI.

The Diſtance of a Place from the firſt Meridian, 1121
meaſured on a Circle of Latitude that goes through a Place, is called the Longitude of the Place.

Aſtronomers refer every thing to the Meridian of 1122
the Place in which they make their Obſervations.

In explaining the Phænomena which relate to the ſeveral Parts of the Surface of the Earth, we ſhall conſider the Obſerver going from the Pole

to

to the Æquator; and firſt only take Notice of the diurnal Motion.

1123 *Plate* XXIII. *Fig.* 3.] When the Spectator is at S, in the very Pole of the Earth T, the cœleſtial Æquator E *e* coincides with the Horizon, and the Pole of the World P is in the *Zenith*; in that Caſe, becauſe the Circles which are parallel to the Horizon, are alſo parallel to the Æquator; all the heavenly Bodies appear to be carried by
*1083 a Motion parallel to the Horizon, * in Circles which are repreſented by the Lines A *a*, B *b*. *The heavenly Bodies in the Hemiſphere* E P *e never ſet, and the others are never viſible. The Ho-*
1124 *rizon in this Situation is ſaid to be parallel, or this Situation is called a parallel Sphere.*

1125 *Plate* XXIII. *Fig.* 4.] *If an Obſerver* upon the Earth T *recedes from the Pole*, and is at S, *the Horizon is ſaid to be oblique, or the Sphere is oblique*; then the Axis P *p* is inclined to the Horizon *h h*, ſo much the more as the Obſerver is farther from the Pole.

Definition XVII.

1126 *The Angle, which the Axis of the Earth makes*
*1105 *with the Horizon, is called* the Height of the Pole.*

1127 This *Height of the Pole is equal to the Latitude.* The Height of the Pole is the Angle P T *h*, whoſe Meaſure is the Arc P *h*; the Latitude is meaſured by an Arc, which upon the Earth cor-
*1118 reſponds to the Arc Z E in the Heavens: * But it is equal to the Arc P *h*; for the Complement of each of them, to a Quarter of a Circle, is the Arc Z P.

1128 *In this Poſition of the Obſerver*, becauſe the Æquator is inclined to the Horizon, *all the heavenly Bodies are carried by the diurnal Motion in Circles inclined to the Horizon*, repreſented by the Lines A *a*, B *b*.

Some

Some of the heavenly Bodies riſe and ſet at every Revolution of the Earth; namely, thoſe which are between the Parallels to the Æquator B *b* and *b i*; becauſe all the Paralliels between thoſe Two are cut by the Horizon. 1129

The Planes of the Æquator and the Horizon go through the Center of the Earth; therefore theſe Circles cut one another mutually into two equal Parts, and Half of the Æquator is above the Horizon; therefore *the heavenly Bodies, which are in the Æquator, are above the Horizon during half a Revolution of the Earth about its Axis*; * and, on Account of the Equability of the Motion about the Axis, *are inviſible during an equal Time.* 1130 *1082

Theſe alſo riſe due Eaſt, and ſet due Weſt (that is, in the very Points of the Eaſt and Weſt;) for the Section of the Planes of the Æquator and the Horizon, is perpendicular to a Plane perpendicular to both theſe Planes; and this laſt Plane is the Plane of the Meridan of the Place.* Wherefore the above-mentioned Section is perpendicular to the Meridian Line, * and conſequently goes through the Eaſt and Weſt Points.* 11 *1078 1116 *1117 *1102

Bodies between the Equator and a Parallel B *b*, *which touches the Horizon*, as in the Circle A *a*, *continue longer above than below the Horizon*; *and this Difference is ſo much the greater, the more the Circle* A *a approaches that Pole, which is above the Horizon.* On the contrary, *as the Body goes towards the oppoſite Pole, its Time of Continuance above the Horizon is the longer.* 1103 1132 1133

This Inequality of the Time that a Body is above and below the Horizon encreaſes as the Height of the Pole does, becauſe of the Diminution of the Angle made with the Horizon by the Æquator and its Parallels. 1134

Bodies, whoſe Diſtance from the Pole is equal to the Height of it, never ſet; for ſuch is the Diſtance 1135

of

of the Circle B *b*, which touches the Horizon, but has no Part of it below the Horizon.

Bodies, leſs diſtant from the Pole, do not ſo much as come down to the Horizon.

1136 It appears by the ſame Reaſoning, that *Bodies, whoſe Diſtance from the oppoſite Pole does not exceed the Height of the Pole*, never riſe above the Horizon, and *are always inviſible.*

1137 Bodies, whoſe Diſtance E Z from the Æquator is equal to the Height of the Pole, go through the Zenith Z; for E Z is equal to the Latitude of the Place to which the Height of the Pole is *1126 equal. *

1138 *Plate* XXIII. *Fig.* 5.] *When a Spectator* S has receded as far as he can from the Pole, he *comes to the Æquator*, whoſe Points are equally diſtant *1075 from each Pole; * then the Axis P *p* is in the Ho- 1114 rizon, with which the Æquator makes a right *1075 Angle,* for which Reaſon the *Horizon is ſaid to* 1114 *be Right*; or this is called a *Right Sphere.*

The Horizon cuts into two equal Parts all the Circles, that are parallel to the Æquator, which are repreſented by the Lines A *a*, B *b*; therefore

1139 *all the heavenly Bodies, at every Revolution of the Earth, riſe, and ſet, and are viſible and inviſible during equal Times.*

1140 *The Æquator itſelf goes through the Zenith, and therefore all the Bodies that are in it paſs through it alſo.*

If what we have explained concerning the Diurnal Motion be applied to the Bodies of whoſe other apparent Motions we have ſpoken before, the Phænomena will be eaſily determined from the Motions joined together: Thoſe that relate to the Sun are more remarkable than the reſt, and therefore more particularly to be explained.

De-

Definition XVIII.

We call a Natural Day the Time elapſed between the Receſs of the Sun from the Meridian of a Place, and its next Return to the ſame Meridian. 1141

This Day differs from the Time of the Revolution of the Earth about its Axis, which Times would be equal, if the Sun appeared immoveable amongſt the fixed Stars; but whilſt by the Diurnal Motion, in the Time of one Revolution of the Earth about its Axis, the Sun is carried round from Eaſt to Weſt, that is, *in Antecedentia*,* it is carried by a contrary Motion in the Ecliptic,* whereby it comes later to the Meridian. 1142 *1080 *996

But as the Sun does not every Day go through an equal Space in the Ecliptic,* all the *Natural Days* do not equally exceed the Revolution of the Earth about its Axis; therefore theſe Days are *unequal to one another.* *997 1143

Natural Days are unequal alſo upon another Account, namely, by reaſon of the Inclination of the Ecliptic in reſpect to the Æquator; whence it follows, that the Annual Courſe of the Sun is unequally inclined to the Æquator in different Points; and, though the Sun ſhould equally go forward every Day in the Ecliptic, the natural Days would not equally exceed the Time of the Revolution about the Axis; for if the Motion of the Sun be reſolved into two Motions,* of which the one is parallel to the Æquator, and the other perpendicular to it, the firſt is only to be conſidered in determining the Exceſs above-mentioned, and that it is unequal, is plain from the different Inclination above-mentioned. *192

Theſe two Cauſes of Inequality often concur, and often act contrarywiſe.

Every Natural Day is divided into twenty-four equal Parts which are called Hours. Each Hour is 1144

divided into ſixty Minutes; and each Minute into ſixty ſecond Minutes, or Seconds; and ſo on. That *theſe Parts of Time vary in different Days*, appears
*1143 plainly from what has been * ſaid; they are by Aſtronomers reduced to Equality, by conſidering the Number of Hours in the whole Revolution of the Sun in the Ecliptic, and dividing the whole Time into as many equal Parts as there are Hours, twenty-four of which are taken for one Day.

1145 *The Time, whoſe Parts are* by this Method *reduced to Equality, is called Mean Time, and that Reduction is called the Æquation of Time.*

1146 *We always make uſe of the Days and Hours of the Mean Time in determining the Periods of the heavenly Motions.*

Definition XIX.

1147 The Artificial Day *is the Time that the Sun ſtays above the Horizon.*

We always ſpeak of it, when we mention Day
1148 in Oppoſition to Night. *In determining the Length of Artificial Days, we ſhall not attend to the Æquation of Time.*

1149 *The* Crepuſculum *always comes before the Sun's*
1150 *Riſe, and follows its Setting; this is that dim Light which we commonly call Morning and Evening* Twilight.

1151 *The Twilight is produced by the Atmoſphere, which is enlightened by the Sun's Rays, and whoſe Particles reflect the Light* every Way; from whence ſome Rays come *to us, though the Sun be depreſſed eighteen Degrees below the Horizon.*

1152 *In the parallel Sphere*, that is, to all thoſe that
*1138 dwell under the Æquator, * *the Days and Nights*
*1139 *are equal to one another all the Year round*, * and
1144 are of twelve Hours.

1153 *In the oblique Sphere the Days are longer or ſhorter, according to the different Diſtance of the Sun from the*

Plate 23

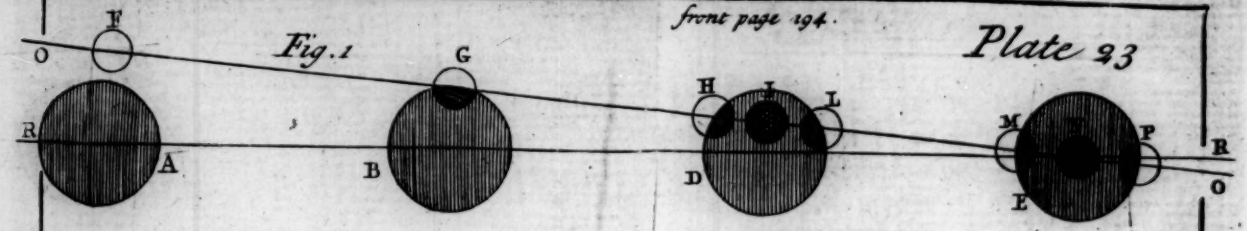


Fig. 1

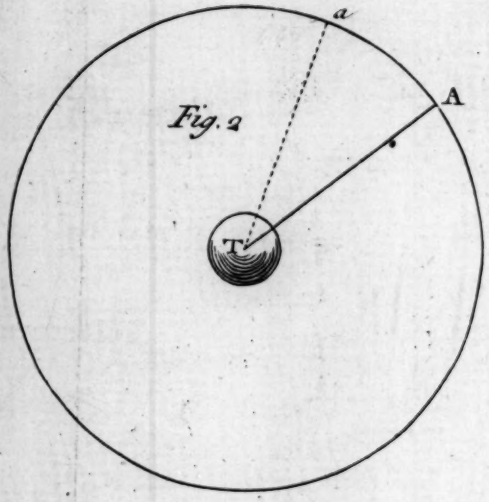


Fig. 2

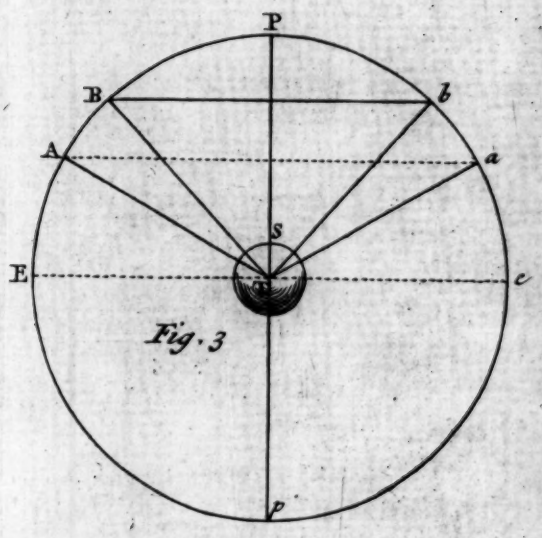


Fig. 3

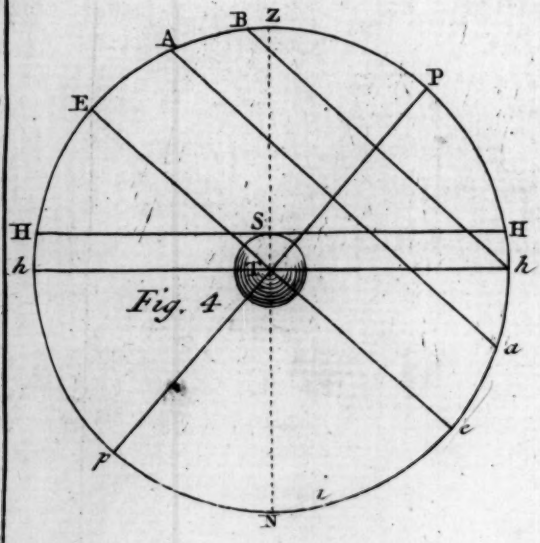


Fig. 4

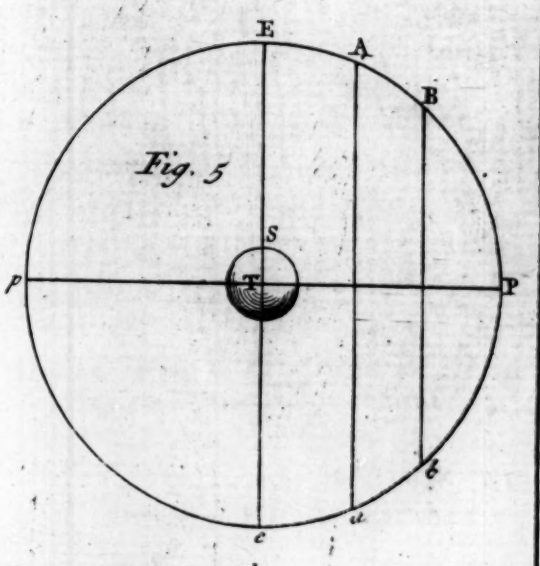


Fig. 5

Vol. 2.

the Æquator, towards either Pole;* for the Sun recedes from the Æquator towards the Poles 23 Degr. 29 Min.*

The Sun is in the Æquator about the 11*th of* March, *and the* 12*th of* September, *and then the Day is equal to the Night*,* *which happens all over the Earth, except juſt at the Poles.*

Definition XX.

Thoſe Points of the Ecliptic, in which it is cut by the Æquator,* *are called the* Æquinoctial *Points*; becauſe the Sun is in thoſe Points, when the above-mentioned Equality of Day and Night happens.

Definition XXI.

Theſe Points of the Ecliptic, in which the Tropics touch that Circle,* *are called the* Solſticial *Points*; becauſe for a few Days, when the Sun comes to thoſe Points, and goes beyond them, it does not ſenſibly change its Declination, and the Length of the Days not ſenſibly vary.

Under the Poles, if there be any Inhabitants there, they can only once in a Year ſee the riſing and the ſetting Sun, and *only one Day with one Night make up their whole Year.* The Sun continues above the Horizon all the while it goes through one Half of the Ecliptic;* the reſt of the Time it is hid under the Horizon. But yet *their Day is lengthened upon account of the Refraction*;* *and the Twilights laſt very long*, for they laſt as long as the Declination of the Sun towards the hidden Pole does not exceed 18 Degr.*

At the Arctic Pole, in the firſt ſix Signs, from *Aries* to *Libra*, the Sun is above the Horizon; therefore at that Pole *the Day exceeds the Night nine Natural Days*,* *beſides the Diminution of the Night on Account of the Refraction.**

These general Things which relate to the different Positions of the Horizon being explained, some more particular Things are to be examined.

1159 *The whole Surface of the Earth is divided into five Zones.* The first *is contained between the two Tro-*
1160 *pics* T T, *t t*, (Plate XXIV. Fig. 2.) *and called the* Torrid Zone; *there are* two Temperate Zones, *and* two Frigid Zones. The Northern Temperate Zone *is terminated by the* Tropic of *Cancer* T T, and the Arctic Polar Circle A A. The
1161 Southern Temperate Zone *is contained* between *t t*, the Tropic of *Capricorn*, and the Polar Circle
1162 *a a. The Frigid Zones are circumscribed by the Polar Circles, and the Poles are in the Centers of them.*

1163 *In the Torrid Zone, twice a Year, the Sun goes*
*1137 *through the Zenith at Noon.** For the Elevation
1160 of the Pole is less than 23 Degr. 29 Min. and the
1127 Distance of the Sun from the Æquator towards the Pole, which is above the Horizon, is twice in
1087 a Year equal to the Height of the Pole. For
1088 which Reason also in the Limits of that Zone,
1164 namely *under the Tropics, the Sun comes to the*
*1087 *Zenith only once in a whole Year.**

1089 *In the Temperate and Frigid Zones,* the least
1165 Height of the Pole exceeds the greatest Distance
1087 of the Sun from the Æquator; and therefore to
1162 their Inhabitants *the Sun never goes through the*
1162 *Zenith.** Yet *the same Day the Sun rises to a greater*
1166 *Height, the less the Height of the Pole is*; because
*1137 thereby the Inclination of the Circles of the Diurnal Motion with the Horizon is less.

1167 *In the Torrid Zone, and in the Temperate Zones,*
*1129 *every Natural Day the Sun rises and sets*; for the
1137 Distance of the Sun from the Pole always exceeds
1168 the Height of the Pole.* Yet *every where but under*
*1087 *the Æquator** *the Artificial Days are unequal to*
1160 *one another*;* which Inequality is so much the

1161 1152 *1132 greater,

greater, the leſs the Place is diſtant from a Frigid Zone. *1124

But *in the Polar Circles*, juſt where the Temperate Zones are ſeparated from the Frigid ones, the Height of the Pole is equal to the Diſtance of the Sun from the Pole, when it is in the neighbouring Tropic; * and therefore in that Caſe, that is, *once a Year, the Sun in its diurnal Motion performs one entire Revolution without going down under the Horizon.* 1169 *1089 1091

But *every where in a Frozen Zone* the Height of the Pole is greater than the leaſt Diſtance of the Sun from the Pole;* therefore, *during ſome Revolutions of the Earth, the Sun* is at a Diſtance from the Pole which is leſs than the Pole's Height, and during all that Time, it *does not ſet*, nor ſo much as touch the Horizon.* But where the Diſtance from the Pole, as the Sun recedes from it, does exceed the Height of the Pole or Latitude of the Place, * the Sun riſes or ſets every Natural Day;* then in its Motion towards the oppoſite Pole, *it ſtays in the ſame Manner below the Horizon*, as was ſaid of the Motion *above the Horizon.** 1170 *1089 1162 *1135 *1127 *1129 1171 *1136

Theſe Times, in which the Sun makes entire Revolutions above the Horizon, and below it, in its diurnal Motion, are ſo much the greater, that is, *the longeſt Day and Night laſt the longeſt, the leſs the Place in the Frigid Zone is diſtant from the Pole*, till at laſt, at the Pole itſelf, they take up the Time of the whole Year. 1172

Form the ſame Cauſes, namely, the Obliquity of the Ecliptic in reſpect of the Æquator, by which are occaſioned all the Things which relate to the Inequality of Days, which is different in different Places; we alſo deduce the Difference of Seaſons, which ſucceed one another every Year; I ſhall ſpeak of them firſt in

reſpect to the Frigid and Temperate Zones, and then in reſpect to the Torrid Zone.

The Rays of the Sun communicate Heat to the Air, not only when they come directly from the Sun, but when they are reflected irregularly
581 from Bodies or the Surface of the Earth.

This Effect is ſo much greater as the Rays ſtrike the leſs obliquely againſt the Surface of the Earth; and that upon a double Account. 1. If you reſolve the Motion of the Light into two
*192 Motions, * one of which is parallel, and the other perpendicular to the Surface of the Earth, the Light acts upon Bodies only by this laſt Motion, which diminiſhes as the Obliquity encreaſes. 2. There are more Rays acting at one Time upon the ſame Part of the Surface of the Earth, the more directly they come upon it.

1173 Hence we deduce, that *the Cauſes of Heat encreaſe when the Days encreaſe*, by the Sun coming towards the Pole, which is above the Horizon; becauſe the Sun does daily aſcend to a greater Height; ſo that to the diminiſhed Obliquity is added the longer Continuance of the Sun above the Horizon, both which concur to the encreaſing of the Heat; the Nights alſo are diminiſhed as the Days encreaſe, and the Height that is produced by Day has leſs Time to decreaſe in.

In the Northern Zones, as follows from this, the Cauſe of the Heat is the greateſt of all when
*1090 the Sun comes to the Tropic of *Cancer*.* *Yet the*
1174 *Heat is not always the greateſt where the Cauſe of Heat is the greateſt*; for the Heat encreaſes as long as that which is acquired by Day is not wholly deſtroyed by Night; for though the daily Agumentations be diminiſhed, as long as there is an Augmentation the Heat encreaſes.

1175 The moſt intenſe Cold is not upon the ſhorteſt Day,

Day, in which the Obliquity of the Sun's Rays is the greateſt, and the Abſence of the Sun the longeſt; but the Cold encreaſes, as long as the Diminution of Heat does laſt; concerning which one may reaſon in the ſame manner as concerning the Encreaſe of Heat.

The Year is divided into four Seaſons; the hotteſt 1176
is called the Summer; the coldeſt the Winter; the temperate Seaſon that follows the Winter, Spring; and the Autumn comes in between Summer and Winter.

In the Northern Regions, in the Beginning of 1177
Spring, the Sun appears to be in the Beginning of Aries. *In the Beginning of Summer the Sun comes to the Tropic of* Cancer. *When the Sun enters* Libra, *the Autumn begins. In the Beginning of Winter the Sun performs its diurnal Motion in the Tropic of* Capricorn; all which may be eaſily deduced from 1174
what has been explained.* *1175

In the Southern Regions, the Summer happens 1178
in the Time of the Winter above-mentioned, and they have their Spring whilſt the former have their Autumn; and ſo of the other Seaſons.

The general Cauſes, upon which the Diviſion above-mentioned depends, are often diſturbed by Cauſes relating to particular Places; eſpecially *in* 1179
the Torrid Zone, of which we ſaid we muſt treat of ſeparately. In moſt Places of this Zone *there are only two Seaſons obſerved*, (viz.) *Summer and Winter, which are* chiefly *diſtinguiſhed by dry and wet Weather.*

When the Sun comes to the Zenith of any Place, 1180
there are almoſt continual Rains; upon which Account *the* Heat is diminiſhed, which *Time is referred to, or called Winter.* As the Sun recedes, the Rains diminiſh, *the Heat is encreaſed, and that* 1181
Time is referred to Summer.

1182 *In the Middle of the Torrid Zone there are two Summers, and as many Winters; becauſe the Sun* *1163 *comes up twice to the Zenith.* *

Towards the Sides of the Zone, tho' the Sun comes twice to the Zenith, yet ſince there is but a ſmall Time between its coming to it the firſt and ſecond Time, both the Winters are confounded into one; wherefore only two Seaſons in a Year are obſerved there.

CHAP. IX.

Concerning the Phænomena ariſing from the Motion of the Axis of the Earth.

*952 WE have ſaid that the Axis of the Earth is carried by a parallel Motion *; we have not conſidered a ſmall Motion, whereby it is really moved, of which we ſhall now ſpeak.

The Axis of the Earth, keeping the Inclination
1183 *of* 66 Degr. 31 Min. *to the Plane of the Ecliptic, revolves in* Antecedentia, that is, is ſucceſſively
1184 carried towards all Parts; and its Extremities, (*viz.*) *the Poles of the World deſcribe Circles round the Poles of the Ecliptic*, from Eaſt to Weſt. And *this Revolution is performed in the Time of about* 25000 *Years; which Period is called the Great Year.*

Becauſe the Earth is looked upon as immoveable by its Inhabitants, this Motion is referred to the heavenly Bodies, as has been ſaid of the other Motions. Therefore whilſt the Poles of the World are moved about the Poles of the Ecliptic in *Antecedentia*, and paſs ſucceſſively thro' all the Points that are 23 Degr. 29 Min. diſtant from theſe Poles, theſe Points themſelves, or rather the

the fixed Stars that are in them, come towards the Poles of the World ſucceſſively, and ſeem to be carried in *Conſequentia*, and to deſcribe Circles which are really deſcribed by the Poles of the World about the Poles of the Ecliptic, which, being placed in Centers, alone are at reſt. For together with the Stars above-mentioned the reſt of the Stars (becauſe they keep the ſame Situation in reſpect to one another) * do alſo ap- *923
pear to be moved.

Therefore *the* whole *Sphere of the fixed Stars* 1185
ſeems to move, in Conſequentia, *about an Axis paſſing through the Poles of the Ecliptic*; and each Star apparently deſcribes a Circle parallel to the Ecliptic; by which Motion the Latitude of the Stars is not changed.

The Plane of the Æquator makes a right Angle with the Axis of the Earth; therefore, by the aforeſaid Motion of its Axis, the Section of the Plane of the Æquator, with the Plane of the 1186
Ecliptic, is moved round; wherefore *the firſt Points of* Aries *and* Libra *, which are always op- *1085
poſite, *move through the whole Ecliptic Line in the Space of about* 25000 *in* Antecedentia: Yet they they are looked upon as immoveable by the Inhabitants of the Earth, who imagine that the fixed Stars themſelves are moved in *Conſequentia.* * *1185

CHAP. X.

Concerning the fixed Stars.

WE have ſaid that the fixed Stars are lucid Bodies, removed ſo far off, that their Diſtances can be compared with no Diſtances in the

1187 the Planetary Syſtem. For *Aſtronomers have not been able, by their niceſt Obſervations, to obſerve the Poles of the World carried out of their Place in the annual Motion of the Earth*, although they deſcribe Circles in the Heavens which are equal to
952 the Earth's Orbit.

Definition I.

1188 This Motion of the Pole is called *the Annual Parallax.*

That the fixed Stars are at an immenſe Diſtance, is alſo proved by Obſervations with the Help of
1189 Teleſcopes. *If any fixed Star*, even the lucid and conſpicuous, *be beheld with a Teleſcope*, through which the Diameter of the Sun would appear equal to the Diameter of the Earth's annual Orbit, *it will appear to be a lucid Point, without any ſenſible Magnitude*; for all the fixed Stars appear leſs when they are ſeen through Teleſcopes than they do to the naked Eye; for it is only their Twinkling which makes them appear to have any ſenſible Magnitude.

1190 *That the Stars may be diſtinguiſhed, they are referred to various Figures, which are imagined in the Heavens, and are called Conſtellations.*

1191 *Twelve Conſtellations are imagined to be in the Zodiac, which are called the Signs of the Zodiac*; they receive their Names from the Animals or
1192 Things which they repreſent: *Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, Sagittarius, Capricornus, Aquarius, Piſces. Theſe* Signs have *given their Names to twelve Parts of the E-*
*999 *cliptic*, of which we have ſpoken before.*

In the Time of *Hipparchus*, the Sections of the Ecliptic and Æquator were between the Conſtellations of *Piſces* and *Aries*, and *Virgo* and *Libra*, and the Conſtellations gave their Names to thoſe Parts

Parts of the Ecliptic, which paſſed through each Conſtellation. *And the Parts of the Ecliptic, ſuppoſing the Beginning of* Aries *and* Libra, *in the Interſections of the Æquator and the Ecliptic, have kept the Names which they had* at that Time, *tho' theſe Interſections be carried from their old Places*; * whence the Sun is ſaid to be in *Taurus*, when it moves amongſt the Stars of the Conſtellation *Aries*. 1193 *1186

The Zodiac ſeparates the North Part of the Heavens from the South Part.

In the Northern Region are the following Conſtellations; *the leſſer Bear, the greater Bear, the Dragon, Cepheus, the Hounds, Bootes, the Northern Crown, Hercules, the Harp, the Swan, the Lizard, Caſſiopeia, Camelopardus, Perſeus, Andromeda, the Triangle, the leſſer Triangle, the Fly, Auriga, Pegaſus, or the Flying-Horſe, Equuleus, the Dolphin, the Fox, the Gooſe, the Arrow, the Eagle, Antinous, Sobieſky's Shield, Serpentarius, the Serpent, Mount Mænalus, Berenice's Hair, the leſſer Lion, the Linx.* 1194

In the Southern Region of the Heavens, are the following Conſtellations, many of which are inviſible to us: * *namely the Whale, the River Eridanus, the Hare, Orion, the great Dog, Rhinoceros, the leſſer Dog, the Ship Argo, Hydra, the Sextant of Urania, the Cup, the Crow, the Centaur, the Wolf, the Altar, the Southern Crown, the Southern Fiſh, the Phœnix, the Crane, the Indian, the Peacock, the Bird of Paradiſe, the Southern Triangle, the Croſs, the Fly, the Chamæleon, King* Charle's *Oak, the flying Fiſh, the* Toucan, *or* American *Gooſe, Hydrus, or the* Water-Serpent, *Xiphias, or* the Sword-Fiſh. 1195 *1131

Definition II.

The Stars, which are between the Conſtellations, 1196 *are called* unformed Stars.

The Stars are not equally lucid, and they are 1197 *referred* by Aſtronomers *to ſix Claſſes*, the moſt lucid

cid are called Stars of the firſt Magnitude; others are ſaid to be Stars of the ſecond Magnitude, others of the third, &c. to the ſixth Magnitude.

1198 *Some are not referred even to this laſt Claſs, and are called Nebulous Stars.*

1199 *There is* alſo *a* certain *Zone* or Belt obſerved *in the Heavens, which* is not every where of the ſame Breadth, and goes round the whole Heavens, and in ſome Places is ſeparated, ſo as to become dou-
1200 ble. From its Colour it *is called the milky Way. It* is plain from Obſervations, by the Help of the Teleſcope, that this Way is *an Aſſemblage of innumerable fixed Stars, which cannot be ſeen by the naked Eye,* either becauſe they are leſs than the other Stars, or more diſtant.

1201 *Towards the Antarctic Pole there are two Nubeculæ, of the ſame Colour as the Milky Way, which are alſo Heaps of ſmall Stars,* and cannot be ſeen without a Teleſcope. Beſides the Stars, which are obſerved in theſe Nubeculæ, and in the Milky
1202 Way, *to whatſoever Part of the Heavens you point the Teleſcope, you may diſcover ſmall Stars in a great Number, which are not viſible to the naked Eye.* Very often an Heap of Stars appears to the naked Eye to be but one Star.

1203 *Amongſt the Stars, ſome are viſible and inviſible by Fits, and obſerve regular Periods*; others are ſucceſſively ſometimes more lucid, ſometimes of a duller Light, and to be ſeen only by the Help of a Teleſcope, and that at certain Times.

1204 Yet *they are not equally bright at every Period. Sometimes Stars have appeared ſuddenly, exceeding the brighteſt in Light, which afterwards, ſucceſſively decreaſing, have vaniſhed in a ſhort Time, and ſtill remain inviſible.*

1205 Beſides the Stars, *we obſerve in the Heavens ſeveral whitiſh Spots, which are in ſome Meaſure lucid,*

and

and inviſible to the naked Eye; their Light is referred to the Stars which are in them, or they are looked upon as nebulous Stars.

What theſe Spots are, cannot be determined; perhaps they are a Congeries of Stars, which have the ſame Relation to the Teleſcopic Stars, as thoſe which form the Milky Way, have to thoſe which are ſeen to the naked Eye.



BOOK IV.

BOOK IV.

PART II.

The Phyſical Cauſes of the Celeſtial Motions.

CHAP. XI.

Concerning univerſal Gravity.

HAving explained the Motions of the heavenly Bodies, and the Phænomena ariſing from them, we muſt now examine by what Laws theſe Motions are performed.

We have before laid down the Laws according
124 to which the Motions of Bodies are directed.
125 If we add one to theſe, we ſhall ſee the whole
126 Contrivance by which that vaſt Machine, the Planetary Syſtem, is governed.

1206 The Law, to be added to the reſt, is this. *All Bodies are mutually heavy* (or gravitate) *towards*
1207 *each other. This Gravity is proportional to the Quan-*
1208 *tity of Matter: At unequal Diſtances it is inverſly as the*

the Square of the Diſtance: That is, all Bodies mutually attract or tend towards each other, with the Force which belongs to each Particle of Matter acting upon each Particle; and the Force, with which a Body acts upon others, is compounded of the joint Forces of all the Particles of which the Body conſiſts; ſo this Force encreaſes in the ſame Proportion as the Quantity of Matter, and is unchangeable in every Particle; it is always the ſame at the ſame Diſtance; but the Diſtance encreaſing, the Force decreaſes as the Square of the Diſtance encreaſes.

We call this Force Gravity, when we conſider a Body which of itſelf tends towards another; becauſe this Force is called by this Name near the Earth's Surface.* 1209 *73

But when we conſider a Body, towards which another tends, we call this Force Attraction. We mean the ſame Effect by theſe Names, and nothing but the Effect; for ſince all Gravity is reciprocal,* it is the ſame to ſay, all Bodies gravitate mutually towards one another, as that Bodies mutually attract one another, or mutually tend towards each other. 1210 *126

We look upon this Effect as a Law of Nature*, becauſe it is conſtant, and its Cauſe is unknown to us, and cannot be deduced from Laws that are known, as we ſhall ſhew by and by. Now, that there is ſuch a Gravity, is to be proved from Phænomena. *4

All the Primary Planets are kept in their Orbits by Forces, which tend towards the Center of the Sun*; therefore there is a Force by which the Planets are carried towards the Sun, and whereby the Sun tends reciprocally towards each of them*: *That is, the Sun and Planets gravitate mutually towards each other.* *944 226 1211 *126

After

1212 After the ſame Manner it is plain, that *the Satellites of Jupiter and Saturn gravitate towards each*
*966 *other*; *as alſo that the Satellites of Saturn gravi-*
226 *tate towards their Primary Planet, and that towards*
126 *them.**

1213 *The Moon and the Earth* alſo *gravitate towards*
*966 *each other.**
226 *All the Secondary Planets gravitate towards*
126 *the Sun.* For they are all carried by a regular
1214 Motion about their Primary Planets, as if the Primary Planets were at reſt; whence it is plain, that they are carried about by the common Motion with the Primary Planets; that is, that the ſame Force, by which the Primary Planets are every Moment carried towards the Sun, acts upon *the Secondary ones*, and that they *are carried towards*
1215 *the Sun with the ſame Celerity as the Primary Planets.* Even the Irregularities of the Secondary Planets, which are ſo ſmall, as only to be ſenſible with reſpect to the Moon, confirm this Gravity of the Secondary Planets towards the Sun; for we ſhall ſhew hereafter, that all the Irregularities are cauſed by the Change of the Moon's Gravity towards the Sun, at a different Diſtance; and becauſe the Lines, in which the Earth and Moon tend towards the Sun, are not altogether parallel.

1216 From the Gravity of the Secondary Planets towards the Sun, it follows, that *the Sun gravitates*
*126 *towards them.**

1217 In reſpect of the Gravitation of the Primary Planets towards one another, Aſtronomers have obſerved, that *Saturn* changes its Way when it is neareſt to *Jupiter*, which is far the greateſt of all the Planets; ſo that it is plain from immediate Obſervations, that *Jupiter and Saturn gravitate towards each other.*

Jupiter

Jupiter alſo in this Caſe, as *Flamſteed* has obſerved, diſturbs the Motion of *the Satellites of* Saturn, attracting them a little to itſelf; which proves that theſe Satellites *gravitate towards* Jupiter, *and* Jupiter *towards them.* From all which Conſiderations * compared together, it follows, that the ſeventeen Bodies, of which the Planetary Syſtem is made up, mutually gravitate towards each other, although no immediate Obſervations can be made concerning the Gravitation of each particular one towards the reſt.* 1218 *1211 1212, 1213, 1214, 1216, 1217, 1218. *7

The ſecond Part of the Law is,* that Gravity is proportional to the Quantity of Matter; that is, that all the Particles of Matter gravitate towards each other; and therefore that the Law of Gravity is univerſal, and that every Body acts upon all other Bodies; which is deduced from Phænomena. *1207

The Forces of Gravity are as the Qualities of Motion which they generate, * and theſe Quantities, in unequal Bodies that are equally ſwift, are to one another as the Quantities of Matter; therefore ſince unequal Bodies, at the ſame Diſtance from the attracting Body, move equally ſwift by Gravity, * it is evident, that the Forces of Gravity are proportional to the Quantity of Matter. We find the ſame in all Bodies *near the Earth's Surface*, which have a Gravitation towards the Earth, proportional to their Quantity of Matter.* But *the mutual Gravity of* all theſe *Bodies towards one another is not ſenſible*; becauſe it is exceeding ſmall in reſpect of their Gravity towards the Earth; and therefore cannot diſturb their Motion ariſing from their Gravity towards the Earth; * at leaſt, ſo as to make any ſenſible Change in the Direction of their Motions. 1219 *58 *62 *1215 1220 *79 *190

We ſhall preſently ſhew, by another Method, that this univerſal Gravity of all the Particles of Matter, whereby they act upon one another,
1222 may be proved from Phænomena.

The third Part of the Law, which we examine, is, that Gravity decreaſes when the Diſtance encreaſes, and is inverſly as the Square of the Diſtances, which alſo follows from Phænomena.

1221 Bodies, upon which Gravity acts according to their Quantity of Matter, as in our Syſtem, are moved with an equal Celerity in the ſame Circumſtances, as we ſaid before; ſo that it is no Matter, whether the Bodies are greater or leſs; and they are moved as if they were equal. But in this Caſe, if the Force towards a Point decreaſes in an inverſe Ratio of the Square of the Diſtance from that Point, and the Bodies move at various Diſtances from it, and are kept in Circles by that Force; the Squares of the Periodical Times will be to one another, as the Cubes of the Di-
239 ſtances. Which is demonſtrated by Geometers to obtain (in reſpect of the mean Diſtances) in Elliptic Lines, whoſe Forces are directed to their *Foci*. But this is the Caſe in Bodies which revolve about the *Sun*, *Saturn* and *Ju-*
*974 *piter*; * whence it follows, that the Force of Gravity, receding from the Centers of theſe Bodies, decreaſes in an inverſe Ratio of the Squares of the Diſtances.

1222 By this Reaſoning, ſuppoſing Gravity proportional to the Quantity of Matter, we demonſtrate, that it decreaſes in an inverſe Ratio of the Square of the Diſtance. And by the ſame Reaſoning, ſuppoſing the Diminution of Gravity to be in this Proportion, it follows, that Gravity is proportional to the Quantity of Matter, as is very evident.

But we prove by another Argument, that the Diminution of Gravity, ſo often mentioned, is in an inverſe Ratio of the Square of the Diſtance; ſo that there can remain no Doubt concerning the two Laws of Gravity, which we now treat of.

The Planets are moved in Orbits at reſt *; and are kept in them by Forces, which are directed to an Excentric Point; * but it is plain, that this would not obtain, if the central Force did not encreaſe in an Inverſe Ratio of the Square of the Diſtance.* *1223 *929 *931 *141 243

It follows from the ſame Reaſoning, that receding from the Center of the Earth, Gravity decreaſes according to the ſame Law. For the Moon is retained in its Orbit by a Force which tends towards the Center of the Earth, that is, to an Excentric Point.* And though the Line of the Apſides is not carried by a parallel Motion, its Agitation is ſo ſmall, if we conſider every Revolution, that it may be looked upon here as quieſcent: For if we compute the Force which keeps the Moon in its Orbit ſo agitated, we ſhall find the Diminution of the Force of Gravity, in reſpect of the Moon, to differ very little from an Inverſe Ratio of the Square of the Diſtance; and we ſhalll ſhew hereafter, that this Difference depends upon the Action of the Sun. 1224 *967 966 226

And no Doubt will remain concerning this Diminution, if we conſider, *that the Moon is kept in its Orbit by that very Force, wherewith Bodies are carried towards the Earth, near the Earth's Surface*; which is diminiſhed, according to the Law of Diminution ſo often mentioned. The Mean Diſtance of the Moon is 60½ Semidiameters of the Earth: We have before ſhewn, that a Diameter of the Earth contains 3400669 *Rhynland* Perches; * whence knowing the Periodical Time, 1225 *976

we eaſily diſcover that the Moon, in one Minute of Time, goes through 16425 ½ *Rhynland* Perches of her Orbit. This Arc is not the hundredth Part of one Degree, and may be looked upon as its Subtenſe; therefore the Diameter of its Orbit is to this Arc, as the Arc itſelf is to its Verſed Sine; which is diſcovered to be of 15, 736 *Rhynland* Feet; and it is the Space which the Moon and Earth would go through in one Minute, coming to one another by their mutual Attraction. The Celerity with which a Body comes to another by the Force of Gravity, depends upon the Force with which it is attracted by that other, all whoſe Particles of Matter attract it; therefore the Celerities of the Moon and Earth, as they come towards each other, are inverſly as the Quantities of Matter in them; which is alſo deduced from the equal Quantity of
126 Motion that is in each Body. Therefore by
65 this Proportion we diſcover how much of the aforeſaid Space (15, 736 Feet) is gone through by the Moon: As the Quantity of Matter, in both Bodies, is to the Quantity of Matter in the Earth; ſo is the Space gone through by both Bodies, in their mutual Acceſs towards each other, to the Way gone through by the Moon only. The Quantities of Matter in the Moon and in the Earth, as we ſhall ſhew hereafter, are to one another as 1, to 39, 37; and 40, 37, is to 39, 37, as 15, 736 to 15, 344, the Space gone thro' by the Moon; which therefore would be gone through in one Minute by any Body, which at the Moon's Diſtance ſhould be impelled by Gravity towards the Earth. This Force increaſing in an Inverſe Ratio of the Square of the Diſtance from the Center, the Space gone through in the ſame Time at the Diſtance of a Semidiameter of the Earth, that is, on its Surface, will be

60

$60\frac{1}{2} \times 60\frac{1}{2} \times 15{,}344$, (*viz.*) 56158 Feet; but becauſe in every Motion equably accelerated, as here (for we conſider the Force as removed from the Earth's Center to the Diſtance of its Surface) the Squares of the Times are as the Spaces gone through in the Fall;* by dividing the Number by 60 x 60, that is 3600; we have the Space gone through by a Body in one Second, near the Earth's Surface, by the Force with which the Moon is kept in its Orbit, which is diſcovered to be 15, 6. *Rhynland* Feet. *131

Now if we examine the Gravity which we daily find in all Bodies near the Earth's Surface,* it is plain, from what has been ſaid concerning the Motion of Pendulums,* and from Experiments made upon Pendulums, that a Body in falling goes through 15, 6. *Rhynland* Feet in one Second of Time, and therefore falls with the Force by which the Moon is kept in its Orbit. *72 *157 158

In this Computation we have neglected to conſider the Action of the Sun, becauſe it is ſmall, and ſometimes encreaſes, ſometimes diminiſhes the Gravity of the Moon towards the Earth.

We have conſidered the Centers of the Bodies in examining the Law of the Diminution of Gravity, although Gravity belongs to all the Particles of Bodies; becauſe it is plain by Mathematical Demonſtration, that *the Action of a ſpherical Body (in which, in every Part, the Particles, that are equally diſtant from the Center, are homogeneous, and which is made up of Particles, towards which there is a Gravity that decreaſes, receding from each of them in an Inverſe Ratio of the Square of the Diſtance) is directed towards the Center of the Body, and receding from it, is diminiſhed in the ſame Inverſe Ratio of the Square of the Diſtance:* So that ſuch a Body 1226

acts, as if all the Matter, of which it consists, was collected in its Center. Whence we deduce the following Conclusions.

1227 That *on the Surfaces of Bodies, in which the Matter is homogeneous at equal Distances from the Center, the Gravity is directly as the Quantity of* *1207 *Matter, and inversly as the Square of the Diameter;** *1208 for in these Bodies the Distances from the Center are as the Diameters.

1228 That *on the Surfaces of Bodies that are spherical, homogeneous, and equal, the Gravities are as the Densities of the Bodies*; for the Distances from the Center are equal; in which Case the Forces of *1207 Gravity are as the Quantities of Matter ;* which, *228, in equal Bodies, are as their Densities.*

79 That *on the Surfaces of the Bodies, that are spher-* 1229 *rical, unequal, homogeneous, and equally dense, the Gravities are* inversly as the Squares of the Diame- *1208 ters ;* because the Distances from the Center are *1207 *in the Ratio* of those Diameters,* the Gravities also are directly as the Cubes of their Diameters; for the Quantities of Matter in Spheres are in that Ratio : And the Ratio compounded of that direct Ratio of the Cubes of the Diameters, and the inverse Ratio of their Squares, in the direct Ratio *of the Diameters themselves.*

1230 Therefore *if both the Densities and the Diame-* *ters differ, the Gravities on the Surface will be in a* *1228 *Ratio compounded of the Densities* and the Diame-* *1229 *ters.** Therefore dividing the Gravity on the Surface by the Diameter, you will have *the Den-* 1231 *sity*; which consequently *is in a direct Ratio of the Gravity on the Surface, and an Inverse Ratio of the Diameter.*

1232 *If a Body be placed in a Sphere that is homoge-* *neous, hollow, and every where of the same Thick-* *ness*, wheresoever it be placed, *it has no Gravity*, the opposite Gravities mutually destroying one another

another preciſely: Whence it follows, that *in an homogeneous Sphere*, a Body, coming towards the Center, gravitates towards the Center only from the Action of the Sphere, whoſe Semidiameter is the Diſtance of the Body from the Center, which *Gravity decreaſes in coming towards the Center, in the Ratio of the Diſtance from the Center*; for all Matter, which is at a greater Diſtance from the Center, forms an hollow Sphere, in which the ſeveral Actions on a Body deſtroy each other.* 1233 *1229 *1232

We have ſaid that the Gravity, which we have hitherto explained, is to be taken for a Law of Nature, becauſe we don't know the Cauſe of it; and becauſe it depends upon no Cauſe that is known to us, which will evidently appear, if we attend to what follows.

(Viz.) That *Gravity requires the Preſence of the attracting Body*; ſo the Satellites of *Jupiter*, *ex. gr.* gravitate towards *Jupiter*, whereſoever it be.* 1234 *1212

That *the Diſtance remaining the ſame, the Celerity with which Bodies are carried by Gravity, depends upon the Quantity of Matter in the attracting Body:* *And that the Celerity is not changed, let the Maſs of the gravitating Body be what it will.* 1235 *1207 1236 *1207

Beſides that, *if Gravity depend upon any known Law of Motion, it ought to be referred to a Stroke from an extraneous Body*; *and* becauſe Gravity is continual, *a continual Stroke would be required.* 1237

If there be ſuch a Sort of Matter continually ſtriking againſt Bodies, it muſt of Neceſſity be fluid, and very ſubtile, ſo as to penetrate all Bodies; for Bodies, that are any how ſhut up in others, are heavy.

Now let a Mathematician conſider, whether a Fluid ſo ſubtile as freely to penetrate the Pores of all Bodies, and ſo rare, as not ſenſibly to hin-

der the Motion of Bodies (for in a Place void of Air, the Motion of a Pendulum will be continued very long) can impel vaſt Bodies towards one another with ſo much Force? Let him explain how this Force increaſes in a Ratio of the Maſs of the Body towards which another is car-
1235 ried.

Laſtly, Let him ſhew, what ſeems moſt difficult to me, how all Bodies, in any Situation whatſoever (if the Diſtance, and the Body to-
1236 wards which the Gravitation is, remain the ſame) are carried with the ſame Velocity; that is, how a Liquid which can only act on the Surfaces, either of the Bodies themſelves, or their internal Particles, to which it is not hindered from coming by the Interpoſition of other Particles, can communicate ſuch a Quantity of Motion to Bodies, which in all Bodies exactly follows the Proportion of the Quantity of Matter in them; and which in this Chapter we have proved to obtain every where in Gravity, and which we have
*77 demonſtrated by a direct Experiment, in reſpect
1238 of the Gravity near the Earth's Surface.*

Yet we don't ſay, that *Gravity does not depend upon any Stroke*, but that it does not follow from that Stroke, *according to any Laws known to us*, and we confeſs that we are entirely ignorant of the Cauſe of Gravity.

CHAP. XII.

Of the Celeſtial Matter; where a Vacuum *is proved.*

HAVING explained the Laws whereby the whole Planetary Syſtem is governed, ſeveral Things muſt be firſt laid down, before we proceed to the Phyſical Explication of the Syſtem.

Syſtem. We muſt begin, by ſaying ſomething of the Celeſtial Matter, that is, of the Medium in which the Bodies that make up the Syſtem are moved, which would be done in few Words, if all Philoſophers agreed that there is a *Vacuum*.

We have before proved that a *Vacuum* is poſſible;* now we are to demonſtrate that there is really one. *From only conſidering Motion we can deduce a* Vacuum; and this is a very common and uſual Way of proving it: To ſee the Force of which Argument, we muſt conſider, that indeed all Motions are not impoſſible without a *Vacuum*, but moſt of thoſe which are daily obſerved; which might be fully evinced by a longer Diſcuſſion: But it ſeems to me to be ſo evident from the following Conſideration, that it would be uſeleſs to add much more. *13 1239

The Figure of the leaſt Particles is unchangeable; for the Particle, whoſe Figure may be changed, conſiſts of ſmaller Particles, which are moved in reſpect to each other; and therefore if it has a changeable Figure, it is not one of the leaſt Parts.

But if the Figure of theſe Particles be unchangeable, and a Body can move between them, without ſuch a Separation of the Particles as to leave a void Space, this will depend on the Figure of the Particles, and the Relation which they have to one another, which a Mathematician will not deny: Therefore, if keeping Things in this State (as to their Figure and Relation) the Particles are encreaſed, even in that Caſe Bodies may be moved without a *Vacuum*.

Now ſuppoſing the ſmalleſt Particles encreaſed to the Bigneſs of a Cubic Foot, whatever be their Figure and Relation with the other Parts, which we ſuppoſe encreaſed in the ſame Proportion as the firſt; let any one conſider, whether Bodies

Bodies of any Bigneſs can be carried between thoſe Parts in Right Lines, and in all ſorts of Curves, and yet never ſeparate the Particles ſo as to leave Vacuities between them.

We cannot conceive how the moſt ſubtile Parts are made, and therefore often attribute to them ſuch Properties as do not follow from their Figure; but theſe Errors will be corrected, by imagining the Particles encreaſed.

1240 *We alſo prove a* Vacuum *by an Argument taken from Reſiſtance.*

12 We have ſaid that Matter is inactive; ſome diſpute about the Word, but no Man denies the Thing; whence it follows, that a Body cannot move through a Fluid, without undergoing a Re-
319 ſiſtance, and conſequently a Retardation.* The
*330 Reſiſtance ariſing from the *Inertia* of the Matter (which Reſiſtance alone is here conſidered) depends upon the Quantity of Matter to be removed out of its Place, which is the ſame, whether the Parts of a Fluid be greater or leſs, if the Celerity of the Body remains the ſame: Whence it follows, that in determining what relates to the Reſiſtance, we muſt have no Regard to the Subtility of the Fluid, as long as it cannot go through the Pores of Bodies; for if we come to ſuch a Fineneſs of Parts, that a Fluid ſhall partly penetrate a Body, it will leſs reſiſt the Body.

Now let us ſuppoſe any Ball or ſpheric Body to be moved along in a Medium of the ſame Denſity as itſelf, and ſo cloſe, that the Parts of the Medium cannot paſs through the Pores of the Body; this Body will be retarded every Moment, ſo that its Velocity at laſt will be reduced to half (as may be proved by a Mathematical Demonſtration) before the Body has gone through twice the Length of its Diameter.

In

In order to apply this Propoſition to a Motion in a very ſubtile Fluid, which freely penetrates the Pores of all Bodies, and fills all Places, we muſt conceive a ſpherical Body without any Pores at all; and that ſuch a Body may be ſuppoſed by imagining all the Particles of Matter cloſely joined, no body will deny.

That the Reſiſtance of ſuch a Body in any Fluid does not depend upon the Bigneſs of the Parts of the Fluid, and is the ſame, whether the Parts of the Fluid be equal, or any how unequal, is evident.

If every thing be full of Matter, this Body can only move through a Fluid of the ſame Denſity as itſelf; for it muſt run againſt all the Matter which is in thoſe Places through which it paſſes, and in them the Matter is without Interſtices as it is in the Body; therefore it will loſe half its Velocity, before it has run through the Length of twice its Diameter.

Now let us ſuppoſe the Body to be encreaſed, the Quantity of Matter remaining the ſame, and the Body continuing homogeneous; that is, let there be Pores in the Body, through which the moſt ſubtile Particles of Matter may paſs very freely; and let theſe Pores be equally diſperſed all over the Body. If the Body, thus changed, be moved, the very ſubtile Fluid, of which we ſpeak, will not run againſt the whole Surface, but only thoſe Parts of the Surface which are between the Pores, which Parts being taken together, becauſe we ſuppoſe the Body homogeneous, are equal to the Surface of the Body in the firſt Suppoſition, when we conceived it to be without Pores; for the Body being encreaſed, the Surface has not been changed, but only dilated by the Interpoſition of Pores: So that in both Caſes the Body will undergo the ſame Reſiſtance

ſiſtance from the Impulſe upon the Surface; and the Reſiſtance on the dilated Body is greater from the Fluid running againſt the internal Parts of the Body. Wherefore this Body will ſooner loſe half its Motion in the ſecond, than in the firſt Caſe; that is, before it has run through the Length of two Diameters of the firſt ſuppoſed Bigneſs; and therefore it loſes a greater Quantity of Motion, in going through two Diameters of the Bigneſs ſuppoſed in the ſecond Caſe.

But this is contrary to Experience; for a homogeneous Ball of Gold, or Lead, *&c.* loſes a much leſs Quantity of Motion than what we have mentioned, in Water or Air; whence it follows, that the Suppoſition that all Things are full of Matter, is falſe. Therefore there is a *Vacuum.*

1241 *That there is a* Vacuum *does* alſo *agree with the Phænomena relating to Gravity*; by which it follows that it is proportional to the Quantity of Matter. If all was full of Matter, Gravity would act equally every Way, and the Forces which are directed towards oppoſite Parts would deſtroy one another; and therefore no ſenſible Gravity would be obſerved, which is contrary to Experience.

Theſe being premiſed, we muſt return to the Celeſtial Matter.

1142 The Motions of the heavenly Bodies do not depend upon the Motion of the Celeſtial Mat-
1238 ter, if there be ſuch a Matter;* *whereby is overthrown the Opinion of thoſe which ſay that the heavenly Bodies are carried along by the common Motion of the Matter which fills our Syſtem.* This Opinion is alſo overthrown by the Motion of the Comets: If there was a Medium in the Syſtem which carried about the Planets in its Motion, and alſo the Comets, it would at leaſt ſenſibly diſturb theſe laſt in their Motions, whilſt they come

come almoſt directly towards the Sun, or directly recede from it, or are carried in *Antecedentia*; that is, in a Motion contrary to the Motion of that Matter. Now as this Motion is not diſturbed, but follows the Way which depends upon Gravity, as it is obſerved, it is plain, that if there be any Celeſtial Matter, and that it is in Motion, it does not exert a ſenſible Action on the Bodies of the Planetary Syſtem, which is alſo deduced from the ſmall Reſiſtance of ſuch a Medium; for by comparing the moſt ancient Obſervations with the modern, it does not appear that the Planets are ſenſibly retarded in their Motions. Yet in Air the Reſiſtance is ſenſible; wherefore the Denſity of the Medium, in which the Planets ſhould move, muſt be almoſt immenſly leſs; therefore *the Planetary Syſtem is not* 1243
filled, unleſs it be *by* ſuch *a ſubtile Medium.*

But we may from the Diviſibility of Matter deduce, that a Quantity of Matter, how ſmall ſoever it be, may be diſperſed all over the Planetary Syſtem, leaving but very ſmall Interſtices. * *29

CHAP. XIII.

Concerning the Motion of the Earth.

BESIDES the Queſtion that has been handled in the foregoing Chapter, there is alſo another to be examined, before we proceed to the Explication of the whole Syſtem.

That no Doubt may be made concerning the Syſtem, which has been explained in the firſt Chapter of this Book, we muſt here prove the Motion of the Earth, concerning which it is no Wonder that many have doubted; for the Celeſtial

leſtial Motions cannot be determined by us, but by Obſervations made by Obſervers on the Earth; and the ſame Phænomena appear, whether the Bodies themſelves be moved, or the Spectator
993 be moved; ſo that it is not to be proved by immediate Obſervations, whether the Motion of the Earth is to be referred to the heavenly Bodies or not.

1244 *That the Earth is carried about the Sun, is deduced from the Analogy of the Motions, and from an* Examen *of the Laws of Nature.*

As to what relates to the Analogy of the Motions, it is to be obſerved, that Satellites revolve about *Jupiter* and *Saturn*, which are leſs than the central Body; that the Moon revolves about the Earth, than which it is leſs. *Laſtly*, That the Sun has revolving about it leſs Bodies than itſelf, as *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*. Now if the Earth revolves with the
1245 reſt, then every where *in our Syſtem the leſſer Bodies move about the greater:* Now *there would be an Exception in this Rule, in reſpect of the Sun, if that* vaſt Body *was to go round ſo ſmall a Body as the*
*975 *the Earth.* *

About the Sun, *Jupiter* and *Saturn*, about which ſeveral *Bodies* revolve, thoſe *move the ſloweſt which*
1246 *are moſt diſtant from the central Body*, and according to this Rule, that the Squares of the Periodical Times follow the Ratio of the Cubes of the
974 Diſtances; *which Rule* may be applied to the Earth, if it be carried about the Sun with the reſt of the Planets, as appears, if its Periodical Time (namely the Time in which the Sun appears to perform an entire Revolution) and its Diſtance from the Sun be compared with the Diſtances and Periodical Times of the reſt of the Planets.

Now this Rule *has only one Exception, if the Sun be moved about, the Earth is at reſt.* In this Caſe

Caſe *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*, are ſubject to this Rule in their Motions, as alſo the five Satellites of *Saturn*, and the four Planets that accompany *Jupiter*; only the Moon and the Sun would move above the Earth in a Proportion quite different; and then the Celerity of the Sun would not only be greater than is required by this Law, but its Velocity would at leaſt be ſix and twenty Times greater than that of the Moon, though it be removed to a vaſt Diſtance from the Earth, in reſpect to the Moon's Diſtance: And therefore in this reſpect, the Analogy of the Celeſtial Motions would be diſturbed.

To theſe Arguments I ſhall add others, whereby it will clearly appear, that the Motion of the Earth is a neceſſary Conſequence of the Laws of Nature, which are deduced from Phænomena.

All Bodies gravitate towards one another, * 1247
therefore the Sun and Earth do; but the Motion, whereby theſe Bodies tend towards one another, is deduced from direct Obſervations. Which ſoever of theſe Bodies moves about the other, deſcribes Area's by Lines drawn to the Center of it, proportional to the Times, which is evident from Aſtronomical Obſervations; therefore the Body moved is retained in a Curve by a Force, which is directed towards the Center of the other. * Now as Re-action is always * 226
equal to Action, * unleſs the Laws of Nature, * 126
which obtain conſtantly every where, be wholly overturned, theſe two Bodies tend towards one another with equal Motions; that is, with Celerities that are inverſly as their Maſſes; * which * 65
is alſo immediately deduced from the Law of Gravity. * * 1235

The Quantity of Matter in the Earth is next to nothing, in compariſon to the Quantity of Matter

Matter in the Sun, as we ſhall ſhew in the following Chapter; wherefore the *Sun muſt move very ſlowly whilſt the Earth comes towards it very ſwiftly.*

Whence it follows, that the Earth is carried round the Sun, leſt it ſhould fall upon the Sun by that very violent Motion whereby it is retained in its Orbit.

This Motion of the Earth is alſo deduced from the ſame Principles another Way.

Two Bodies, that are carried towards one another by any Force, will at laſt concur, or continually recede from one another, unleſs each of them be ſo moved, as to have a centrifugal Force equal to the Force whereby it is carried towards the other Body; but as the Bodies, which gravitate towards one another, tend towards
126 each other with equal Forces, or what is the
65 ſame, with Celerities that are inverſly as the
123 Quantities of Matter; theſe Bodies cannot per-
1248 ſevere in their Motions about one another, unleſs both of them be ſo moved, as to have equal centrifugal Forces, which does not happen, unleſs they both revolve in equal Times about their common Center of Gravity: That is, if this Propoſition be applied to the Sun and Earth, unleſs they both move about a Point, whoſe Diſtance from the Center of the Sun is to its Diſtance from the Center of the Earth, as the Quantity of Matter in the Earth is to the Quantity of Mat-
*234 ter in the Sun, they cannot perſevere in their
235 Motions about one another:* This Point or Center of Gravity muſt of Conſequence be very near to the Sun's Center. Now ſince whichſoever of theſe Bodies moves, it perſeveres in its Motion about the other, it follows, that both of them are affected by the Motions above-mentioned, and that the Sun is moved

but

but a little, whilſt the Earth deſcribes a very great Orbit. Whence it follows, that the Motion of the Earth cannot be denied by any one, who reaſons from the Laws of Motion that are deduced from Phænomena.

Having proved *the* annual *Motion of the Earth* 1249
and brought back the Earth amongſt the Planets, there remains but little Difficulty in relation to the Motion of it *about its Axis*; for no body, that believes the annual Motion, doubts of this; a great many, which allow of the Motion about the Axis, deny the annual Motion; therefore it will be enough to obſerve by the By, that all the Planets, concerning which any Obſervation could be made in reſpect of this Motion, do move about their Axes; and that the Earth has ſuch a Motion, *the uniform diurnal Motion in Bodies, at any Diſtances, does plainly enough ſhew.* To which we muſt add, that the Celerity of the fixed Stars, going through one whole Revolution leſs than 24 Hours, can hardly be more probable than it is conceivable.

This Motion alſo is diſagreeable to the Nature of all *the heavenly Bodies*; for, *if they are car-* 1250
ried round, they muſt every Day, with an equable Motion, deſcribe Circles that have the Earth for their Center; that is, they muſt, by Lines drawn to the Center of the Earth, ſweep through Area's proportionable to the Times, and be retained in their Orbits by Forces which are directed towards the Center of the Earth,* and by *226
which (by reaſon that Action and Re-action ** *126
are equal) *the Earth* muſt alſo be continually attracted towards thoſe Bodies; ſo that it *muſt neceſſarily be agitated by a very violent Motion*; whence it appears that the diurnal Motion muſt not be referred to the heavenly Bodies, but to the Rotation of the Earth about its Axis.

1251 Thoſe that obſtinately affirm that the Earth is at Reſt, object that Bodies, upon the Surface of the Earth, muſt (on account of their centrifugal Force) recede from the Earth, along a *217 Tangent to a Circle parallel to the Æquator.* We anſwer, that the Bodies in the Places where they are, are carried round with the ſame Motion as the Surface of the Earth; and therefore that, in reſpect of the Points of the Surface, they endeavour to recede in Lines perpendicular to the *223 Axis;* but alſo that Bodies by Gravity tend to the *1226 Center of the Earth;* and therefore by a Motion compounded of both theſe, the Body is continu- *190 ally moved, or endeavours to move;* but becauſe 198 the firſt Motion is extremely ſmall in reſpect of the other, a heavy Body is turned but very little out of its Direction towards the Center, and the Gravity is a little diminiſhed, ſo much the more as the Place is more diſtant from the Pole; which agrees with Experience. We ſhall hereafter ſhew, when we come to ſpeak of the Figure of the Earth, that the above-mentioned Direction of heavy Bodies is every where directed perpendicularly to the Surface of the Earth. A Body, which is thrown upwards, is acted upon, not only by the Motion wherewith it is thrown up; but it is alſo carried by the Motion that is impreſſed to the Perſon or Machine that impels the Body; that is, it is carried by the Motion which is common with the Surface of the Earth; and therefore the Body moves in the ſame Line (the Line being carried on with the Surface of the Earth) as it would do if the Earth was at Reſt.

CHAP.

CHAP. XIV.

Concerning the Denſity of the Planets.

BEFORE we proceed to the Phyſical Explanation of the Syſtem, we muſt determine the Quantities of Matter in ſome Bodies, and their Diverſities; which being known, the Effects of the Laws, by which theſe Bodies are governed, will more eaſily appear.

The Quantities of Matter, in different Bodies, are to one another, as the Gravities at the ſame Diſtance from theſe Bodies;* which Gravities are to one another inverſly as the Squares of the Periodical Times of the Bodies revolving about thoſe different Bodies at the ſame Diſtance.* By multiplying the Quantities which are in this Ratio by the ſame Quantity, (*viz.*) by the Cube of this Diſtance, the Ratio of theſe Quantities will not be changed; which are therefore to one another as the Quotients of the Diviſions of the above-mentioned Cube, by the Squares of the Periodical Times aforeſaid: But the Quotient of ſuch a Diviſion is found for any Body, by dividing the Cube of the other Diſtance; let it be what it will, by the Square of the Periodical Time of the Body revolving at that Diſtance; for ſuch Quotients are equal to one another, for all Bodies that revolve about the ſame Body at any Diſtances; as follows from the Equality of the Ratio between the Cubes of the Diſtances, and the Squares of the Periodical Times at thoſe Diſtances.* From which we deduce, that *the Quantities of Matter, in any Bodies in our Syſtem, are to one another directly as the Cubes of the Diſtances at which other Bodies revolve about theſe,*

* 1207 * 236 * 974 1252

and inverſly as the Squares of the Periodical Times of theſe revolving Bodies.

Theſe Things are demonſtrated by ſetting aſide the Agitation of the Central Body, whoſe Quantity of Matter is enquired after.

By reaſon of the Sun's Magnitude, in reſpect of *Venus*, *ex. gr.* which alone we conſider of the Planets, the Sun is ſcarce moved by the Action
2135 of that Planet. And *Venus* may be conſidered as moving about a quieſcent Body.

The Satellites of *Jupiter* and *Saturn* are indeed carried by the common Motion along with the Primary Planets, but by reaſon of the Magnitude of the Primary Planets, they are carried about them as about Bodies that are at reſt.

But the Moon acts ſenſibly enough upon the Earth and moves it; wherefore before we can compute the Motion of the Moon by the Help of the
1252 aforeſaid Rule, in order to compare the Quanti-
1253 ty of Matter in the Earth with the Quantities of Matter in the Sun, *Jupiter*, and *Saturn*, we muſt determine *the Diſtance at which the Moon would move about the Earth*, if it was at Reſt (that is, *not carried about by the Action of the Moon*) *in the ſame Periodical Time in which it now performs its Revolution.* Here alſo we don't take Notice of the Motion that is common to the Earth and Moon, by which they are both carried about the Sun.

The Moon perſeveres in its Motion about the Earth; therefore the Earth and Moon are moved about a common Center of Gravity; as follows from what has been demonſtrated concerning the
1248 Earth and the Sun, and the Moon (with that Force with which it tends towards the Earth) revolves in an Orbit whoſe Semi-Diameter is the Diſtance of the Moon from the aforeſaid common

mon Center of Gravity of the Moon and the Earth.

Let L be this Diſtance of the Moon from the common Center of Gravity; T the Diſtance of the Earth from the ſame Center; L + T therefore is the Diſtance of the Moon from the Earth, and is 60½ Semi-Diameters of the Earth; for here we conſider the mean Diſtance. Let D be the Diſtance which we would have, at which the Moon, by its Gravity towards the Earth, would move about the Earth, if it was at Reſt, in the ſame Time in which it is now moved about the common Center of Gravity at the Diſtance L.

By reaſon of this Equality of the Periodical Times, the Force, whereby the Moon would be kept in its Orbit at the Diſtance D, is to the Force whereby it is kept in its Orbit at the Diſtance L, as D to L.* *232

But the Force whereby the Moon would tend to the Earth, and be kept in its Orbit at the Diſtance D, is to the Force whereby it is now kept in its Orbit at the Diſtance L + T, as $\overline{L+T}^q$ to D^q*. Therefore *1208

$$D, L :: \overline{L+T}^q, D^q$$

Conſequently $D^c = L \times \overline{L+T}^q$, and $D^c \times \overline{L+T} = L \times \overline{L+T}^c$: Whence we deduce the following Proportion:

$$\overline{L+T}, D^c :: L+T, L.$$

Therefore L + T, D :: L + T, is to the firſt of two mean Proportionals between L + T and L.

L + T is to L, as the Quantity of the Matter in the Earth and Moon taken together, to the Quantities of Matter in the Earth alone; * *234 which Quantities of Matter, as we ſhall ſhew 235 hereafter, are to one another, as 40, 37. to 39, 37.

39, 37. and the first of two mean Proportionals to these Numbers is 40,035; therefore 40, 37. is to 40,035. as 60½ to the Distance required, which is found to be 60 Semi-Diameters of the Earth.

Concerning this Operation it is to be noted, that the Distance D cannot be discovered, unless the Ratio between the Mass of the Moon and the Earth be known, which cannot be determined unless the Ratio between the Density of the Sun and the Earth be found: To discover which, it is necessary that the Distance D be known. Wherefore D is discovered at first by Trials, and is exactly determined by Approximation. But it is certain, that this is 60 Semi-Diameters of the Earth; because, this being supposed, it is found that the Ratio between the Quantities of Matter of the Moon and the Earth is as 1 to 39, 37. as we shall see hereafter; by making use of which Proportion, this Distance is discovered to be 60 Semi-Diameters, as we have shewn.

These Things being premised, we proceed to the Computation.

The Distance of *Venus* from the Center of the Sun is 723, and its Periodical Time is 5393 *959 Hours.

The Fourth Satellite of *Jupiter* is distant from the Center of *Jupiter* 12, 507. such Parts of which *Venus* is distant from the Sun 723. The Periodical Time of this Satellite is 402 Hours, *971 5 Minutes.*

The Fourth Satellite of *Saturn* is distant from the Center of *Saturn* 9, 292. of the same Parts; *972 and its Periodical Time is 382 Hours 41 Min.*

Lastly, the Distance of the Moon is 60 Semi-Diameters of the Earth from its Center, and

2,909.

2,909. of the aforeſaid Parts. Its mean Periodical Time is 655 Hours, 43 Min.

If you divide the Cubes of theſe Diſtances reſpectively by the Squares of the Periodical Times, you will have, in the Quotients, Numbers which are to one another as the Quantities of Matter in the aforeſaid Central Bodies; * which Quotients are to one another as the following Numbers: 1254 *1252

Quantities of Matter.	*In the Sun.*	*In Jupiter.*	*In Saturn.*	*In the Earth*
	10000.	9, 248.	4, 223.	0, 0044.

We have alſo the Proportion of the Diameters of theſe Bodies from Aſtronomical Obſervations, as follows. 1256

Diameters	*Of the Sun.*	*Of Jupiter.*	*Of Saturn.*	*Of the Earth*
	10000.	1077.	889.	104.

If the Quantities of Matter aboveſaid be divided by the Squares of the Diameters, the Quotients will be to one another as the Weights on the Surfaces of the aforeſaid Bodies;* and theſe Quotients are as the following Numbers. 1257 *1227

Gravities on the Surfaces	*Of the Sun.*	*Of Jupiter.*	*Of Saturn.*	*Of the Earth*	
	10000.	797, 15.	534, 337.	407.	832.

If you divide theſe Numbers by the Diameters, you will have the Proportion of the Denſities of thoſe Bodies.* 1259 *1231

The Quotients, found by theſe Diviſions, are as the following Numbers.

Denſities	*Of the Sun.*	*Of Jupiter.*	*Of Saturn.*	*Of the Earth*
	10000.	7404.	6011.	39214.

1260

We ſhall determine the Denſity of the Moon in the laſt Chapter.

It is not probable that the aforeſaid Bodies are homogeneous. We ſhall ſhew in relation to the Earth, in the 17th Chapter, that it is denſer towards the Center than towards the Surface; from whence it follows, that the Denſities cannot be exactly determined. Wherefore *we* only *determine the mean Denſities*, that is, *which the Bodies would*
1261 *have, if the ſame Bodies, keeping the ſame Quantity of Matter and Bulk which they now have, ſhould become homogeneous.*

1262 *The above-mentioned Proportion* * *between the*
*1260 *Denſities, in reſpect of all the Bodies, and the reſt of the Computations in reſpect of the Sun, Jupiter, and Saturn, are free from any ſenſible Error: When they are compared with the Earth there may be ſome Error*, which muſt be corrected by Obſervations to be made hereafter; for we ſuppoſe the Diſtance of the Moon (which is 60 Semi-Diameters of the Earth) to be 2, 909 ſuch Parts, of which *Venus* is diſtant from the Sun 723, that is of which the
959, 960 Earth is diſtant from the Sun 1000; which Diſtance of the Moon is diſcovered by ſuppoſing the Horizontal Parallax of the Sun 10″, which cannot be looked upon as abſolutely true, although it be deduced from the moſt exact Obſervations that have hitherto been made, of the Parallax of *Mars*, when it is neareſt of all to the Earth, which is too ſmall to leave us without Suſpicion of
1108 ſome Miſtake.

But the Error, in not determining truly the Proportion between the Semi-Diameter of the Earth and the Diſtance from the Sun, does not change the determined Denſity of the Earth, as is deduced from Computations made about it.

For it follows from theſe, that the Denſities of Bodies are to one another in a Ratio compounded

pounded of the direct Ratio of the Cubes of the Diſtances of the Bodies carried about, and the inverſe Ratio of the Squares of the Periodical Times of theſe revolving Bodies;* as alſo of the inverſe Ratio of the Cubes of the Diameters of the Central Bodies whoſe Denſities are required;* the Ratio, compounded of theſe, is compounded of the direct Ratio of a Fraction whoſe Numerator is the Cube of the Diſtance of the revolving Body, and whoſe Denominator is the Cube of the Diameter of the Central Body, and the inverſe Ratio of the Square of the Periodical Time of the Body carried about. But you have ſuch a Fraction, if you know the Ratio between the Diameter of the Central Body and the Diſtance of the revolving Body from that Center, although this Diſtance can be compared with no other; but this Ratio is given in reſpect of the Earth and Moon, as well as in reſpect of the other Bodies; wherefore alſo the Ratio of the Denſity of the Earth to the Denſities of the other Bodies is exactly diſcovered.

*1254 *1257 1259

CHAP. XV.

The Phyſical Explanation of the whole Planetary Syſtem.

IN the firſt Part of this Book we have ſhewn, what are the Motions of the Bodies in the Planetary Syſtem; now we muſt explain how theſe Motions follow from the Laws of Nature;* that is, how theſe Bodies, being once put in Motion, perſevere in thoſe Motions which we obſerve.

Let us conceive the Sun and *Mercury* to be left to themſelves, and they will come together;* but if they be projected, they may revolve about

*124, 125, 126, 1206, 1207, 1208

1263 *1206

a common Center of Gravity in equal Times,
*1248 and deſcribe immoveable Elliptic Lines, * and
1208 perſevere in that Motion; for it is plain, by Ma-
241 thematical Demonſtration in that Caſe, that the Bodies will deſcribe Ellipſes about the common Center of Gravity, ſimilar to that which the one of them could deſcribe with the ſame Forces about the other, if it was at Reſt: This Center,
*235 on account of the Sun's Magnitude, * is very little diſtant from the Center of the Sun itſelf.

Let us conceive beſides, *Venus* to be projected at a greater Diſtance from the Sun, it will a little diſturb the Motion of *Mercury*, which alſo, by its Action upon *Venus*, will turn it a little out of the Way, and both will draw the Sun, ſometimes the ſame Way and ſometimes different Ways; but we find all theſe Irregularities are inſenſible, if we conſider the Magnitude of the Sun; and therefore that theſe three Bodies tend towards a Point that is between them near the Sun, which therefore is very little diſtant from the common Center of Gravity of them all.

If the Earth, *Mars*, and the other Planets be ſucceſſively projected at different Diſtances from
1264 the Sun, the ſame Reaſoning will hold good. Whence it follows, that *all the Planets are revolved about the common Center of Gravity of all the Bodies which compoſe the Syſtem*, which is but little diſtant from the Sun, and that the Planets do not
1265 ſenſibly diſturb one another in their Motions; wherefore *they all deſcribe the ſame Line ſingly, which they would deſcribe about the Sun, if every one of them was alone with the Sun in the Planetary Syſtem*, that is, immoveable Ellipſes: For it is plain, that theſe will be deſcribed by the Force
*1208 of Gravity; * and it is proved by Mathematical
241 Demonſtration, that no other immoveable ex-

centric Lines can be deſcribed by a Central Force acting equally at equal Diſtances.

It will alſo more plainly appear, that all the Planets tend to a Point near the Sun, if we conſider that the Quantity of Matter in the Sun is a thouſand times, and more, greater than the Quantity of Matter in *Jupiter*, which is far the greateſt of all the Planets.* *1255

When all *the Planets move*, though they move 1226
the Sun but little, yet they do move it, and draw it differently according to their different Situation in reſpect of one another; whence there ariſes a ſmall Motion in the Sun, which always depends upon the Motion already acquired, and the Change which happens in it from the Action above-mentioned, which varies every Moment.

It is owing to this Agitation of the Sun, that the 1267
Planets diſturb one another leſs in their Elliptic Motions round the Sun, than if the Sun was at Reſt in the Middle of the Syſtem. If *Jupiter*, *ex. gr.* was equally diſtant from *Mercury* and the Sun, it would attract both thoſe Bodies to itſelf with an equal Celerity;* whence the Situation, in reſpect *1235
of the Sun, is leſs changed than if the Sun was not agitated by this Motion, and *Mercury* only was attracted by *Jupiter*: According to the various Diſtances of *Mercury* and the Sun from *Jupiter*, the one or the other is more attracted, and there is always a leſs Change in their reſpective Situation when both are carried the ſame Way, than if (the Sun being at Reſt) *Mercury* only ſhould be carried towards *Jupiter*.

This Reaſoning may be applied to all the Actions of the Planets, that are more diſtant from the Sun, upon thoſe that are leſs diſtant. As to what relates to the Action of thoſe that are nearer, upon thoſe that are farther from the Sun, according to the different Situation they draw

draw a Planet to the Sun, or drive it from the Sun, and in conſidering one whole reſpective Revolution, that is, the Motion from one Conjunction to another, the Diſturbance is leſs than if the Sun was immoveable.

1268 The Magnitude of the Sun, compared with the reſt of the Bodies of our Syſtem, is the Reaſon (as appears by what has been already demonſtrated) that the Planets diſturb one another but little; but ſince the Magnitude is not infinite, theſe mutual Actions muſt not be wholly overlooked.

We have ſaid, that it appears by Aſtronomical Obſervations, that *Jupiter* alters the Way of
*1217 *Saturn* when it is neareſt to it;* why this Diſturbance is more ſenſible than the reſt, is deduced from the Law of Gravity.

1269 The Actions of *Jupiter* upon *Saturn* when it is neareſt to it, and of the Sun upon the ſame Planet, by which it is kept in its Orbit, are to one another directly as the Quantities of Matter in
*1207 *Jupiter* and the Sun,* (*viz.*) as 9, 248. to 10000,*
*1255 and inverſly as the Squares of the Diſtances of *Jupiter* and the Sun from *Saturn*; that is, directly as 81 to 16; for the Diſtances of *Saturn* and
1270 *Jupiter* from the Sun are almoſt as 9 to 5; wherefore, *when Jupiter is neareſt to Saturn, the* Diſtances of *Saturn* from *Jupiter* and the Sun are as 4 to 9. The Ratio compounded of the two aforeſaid Ratio's is as 749 to 160000, or as 1 to 214. This *Action of* Jupiter *conſpires with the Gravity of* Saturn *towards the Sun, and* therefore *encreaſes* $\frac{1}{214}$ Part: Whence it is no Wonder that the Diſturbance is ſenſible.

We don't here conſider the Force by which *Jupiter* attracts the Sun, for the Orbit of *Saturn* is not changed by it, and what we had to explain was, why Aſtronomers obſerve *Saturn* to be

be turned out of the Way; yet by the Action of *Jupiter* upon the Sun, the Sun is brought nigher to *Saturn*, and the reſpective Situation of theſe Bodies is more diſturbed, than is diſcovered by Aſtronomical Obſervations. The Force with which *Jupiter* in the aforeſaid Poſition attracts the Sun, and with which therefore the Sun is attracted towards *Saturn*, is to the Force with which *Jupiter* attracts *Saturn*, as 16 to 25;* that is, as 479 to 749, which Number expreſſes the Force with which *Saturn* tends towards *Jupiter*, when the Gravity of *Saturn* towards the Sun is expreſſed by 160000. If we collect into one Sum the Forces of *Jupiter*, by which it attracts *Saturn* and the Sun; the Force, by which, from the Interpoſition of *Jupiter*, theſe Bodies tend towards each other, will be to the Gravity of *Saturn* towards the Sun, as 1228 to 160000; but this Gravity is to the Gravity of the Sun towards *Saturn*, as 160000 to 67, 5.* wherefore *the mutual Acceſs, or Approach of the Sun and* Saturn *is to the Encreaſe of this Approach by the Action of* Jupiter *interpoſed*, as 160067 to 1228, or, *as* 130 *to* 1. * 1208 * 1207 1255 1271

This Diſturbance is remarkable, and far the greateſt of any that happens in the Motion of any of the primary Planets: This alſo obtains only in this one Caſe of the Conjunction; for when *Jupiter* recedes from *Saturn*, the Diſturbance of the Motion of *Saturn*, in a ſhort Time, becomes inſenſible.

In the ſame Poſition of *Jupiter*, when it is neareſt to *Saturn*, the Force of *Saturn*, although it be the greateſt of all in this Caſe, does not ſo ſenſibly alter the Way of *Jupiter* about the Sun. The Action of *Saturn*, attracting *Jupiter*, is to its Action by which it attracts the Sun, as 81 to 16;* therefore it attracts *Jupiter* with greater Celerity; and ſince they are both attracted the * 1208

ſame

ſame Way, the Difference of theſe Forces is the Force with which (from the Action of *Saturn*)
*175 *Jupiter* and the Sun are ſeparated from each other*; which is therefore to the Gravity of the Sun towards *Saturn*, as 65 to 16; but this Gravity of the Sun towards *Saturn* is to the Gravity of *Jupiter* towards the Sun, as 4, 223. to
1207 10000, and as 25 to 81*; that is, as 106 to
1255 810000, or as 16 to 122756; therefore the di-
*1208 ſturbing Force of *Saturn* is to the Gravity of *Jupiter* towards the Sun, as 65 to 122756, or
1272 as 1 to 1888; therefore *by the greateſt Action of* Saturn, *the Gravity of* Jupiter *towards the Sun is diminiſhed only by* $\frac{1}{1888}$ *Part*, which Diſturbance is inſenſible.

The other mutual Diſturbances of the Planets are much leſs, as will appear by determining that, which is the greateſt of them all, (*viz.*) that of *Mars* by *Jupiter*, which is diſcovered by the ſame Sort of Computation as the foregoing.

The Diſtance of *Jupiter* from *Mars* and the Sun, when *Mars* is between the Sun and *Jupiter*
961 in the ſame Line, are as 7 to 10; wherefore
962 the Forces with which *Jupiter* attracts theſe
1280 Bodies, are as 100 to 49, the Difference of which Forces is to the Gravity of the Sun towards *Jupiter*, as 51 to 49. This Gravity of the Sun towards *Jupiter*, is to the Gravity of
*1207 *Mars* towards the Sun, as 9, 248 to 1000*, and
1255 as 9 to 100*; that is, as 83 to 1000000; or as
*1208 49 to 590443; and the diſturbing Force of *Jupiter* is to the Gravity of *Mars* towards the Sun, as 51 to 590443; or as 1 to 11577: wherefore
1273 *the Gravity of* Mars *towards the Sun, is diminiſhed only* $\frac{1}{11577}$ *Part by the Action of* Jupiter *when neareſt to it.*

Although

Although theſe Diſturbances, ariſing *from the* 1274
Actions of the Planets upon each other, be very ſmall, and although thoſe which happen in a different Poſition of the Planets do in ſome Meaſure compenſate each other, yet the Proportion in which the Force, which keeps the Planets in their Orbits decreaſes, is a little changed by theſe Actions, ſo that it does not decreaſe exactly in an inverſe Ratio of the Square of the Diſtance: Therefore although the Orbits are at Reſt as to Senſe, *after a great many Revolutions, a ſmall Change is obſerved in their Situation.** *243 929

From all this it follows, that if we ſuppoſe the 1275
Planets at firſt once projected at the Diſtances from the Sun at which they are moved, they will, by the Laws already explained, perſevere in thoſe Motions; and the Excentricity of the Orbits depends upon the Celerity and Direction of the firſt Projection. But theſe Motions may be preſerved very long, by reaſon of the ſmall Reſiſtance of the Celeſtial Matter.

It is alſo plain, why, by Lines drawn to the Center of the Sun, they deſcribe *Areas* proportionable to the Times; namely, becauſe all other Gravities, in the Syſtem, are very ſmall in reſpect to the Gravity towards the Sun*; therefore by this *1265
Gravity alone, it is that they are retained in their Orbits; whence follows this Proportion of the *Areas**. And alſo the Motion in Elliptic Lines, *225
which are carried on very ſlowly, follows from the Law of Gravity; and theſe Lines would alſo be immoveable, if the Planets gravitated only towards the Sun *; but this ſlow Motion of the *241
Orbits is deduced from the Action of the Pla- 1208
nets upon one another.* Now in reſpect to the *1214
Proportion which is obſerved between the Cubes of the Diſtances, and the Squares of the Periodical Times, it is alſo deduced from the Law of Gravity

239 Gravity ; ſo that if we add to theſe what we
1208 *1217 have ſaid of the Deflection of *Saturn*,* nothing
1270 will remain to be explained in reſpect to the primary Planets.

1276 That *the Motion of Comets depends upon the Law of Gravity*, is alſo deduced from Obſervations; and in reſpect of them, as has been ſaid concerning the Planets, the Sun's Gravity prevails, and by that Gravity they deflect from a rectilinear *980 Courſe;* but that the Curvature of their Way
226 depends upon the ſame Gravity, follows from this; That a Body, by that Gravity, will deſcribe an Ellipſe, or a Parabola, or an Hyper-*241 bola ;* which Lines it appears that thoſe Comets
1208 have deſcribed, whoſe Trajectories have been determined.

1277 *The Satellites of* Jupiter *and* Saturn *are moved* *944 *by the ſame Laws about their Primaries, as the*
966 *Primaries are moved about the Sun*;* wherefore the
974 Explication of thoſe Motions * may be alſo refer-*1275 red to them; for in theſe three Caſes, ſmaller Bodies are revolving at different Diſtances about a much greater Body: Namely, Satellites about *Jupiter* and *Saturn* and Primary Planets about the Sun.

1278 *Whilſt ſecondary Planets are moved about a Primary one, it is evident that they may all be moved with one common Motion*, whereby the reſpective Motions with which they are moved, in reſpect of each other, will not be diſturbed, becauſe a Body may at the ſame Time be moved by different Im-*125 preſſions: * The Motion that a Primary Planet has, in common with its Satellites, is the Motion of a Primary Planet about the Sun.

1279 Yet *the Motion of the ſecondary Planets is diſturbed by the Action of the Sun*, towards which they are carried ſometimes faſter, and ſometimes ſlower, according to the different Poſition of the Primary; and they

they alſo often concur towards the Sun's Center in different Directions. Theſe Irregularities, which are very ſmall, cannot be obſerved in the Satellites of *Jupiter* and *Saturn*, though they be really like thoſe which are obſerved in the Motion of the Moon: The leaſt Deviation of this laſt is very ſenſible to us. But that the Irregularities of the Moon exactly follow from the Theory of Gravity, will appear in the next Chapter.

CHAP. XVI.

The Phyſical Explication of the Moon's Motion.

IT is certain that the Moon and Earth having once a projectile Motion given them, they can perceive in their Motion about their common Center of Gravity; * if they be carried any Way by a common Impreſſion directed in parallel Lines, as was ſaid of the Satellites *Jupiter* and *Saturn*, * this Motion will not diſturb the Motion about the common Center of Gravity, which will follow that Direction only, becauſe in reſpect of the two Bodies it is at Reſt. But the Bodies are carried by a Motion compounded of that Impreſſion, and of the Motion about the common Center of Gravity; * that is, they are whirled about that Center as it is carried along, as before its Motion when it was at Reſt. If every Moment new Impreſſions common to both the Bodies act upon them, the Way of the Center of Gravity may be changed every Moment, which Change will be like that which the Bodies themſelves would undergo, if they had no reſpective Motion. 1280 *1263 *1278 *190

Hence we deduce, that if whilſt the Moon and Earth are whirled round their common Center of Gravity, they be both projected, the Way of the Center of Gravity, by the Action of the Sun acting upon both Bodies, is the ſame as a Body, projected in the ſame Manner, would deſcribe about the Sun.

1281 Whence it follows, *that the Moon diſturbs the Motion of the Earth, and that the common Center of Gravity of thoſe Bodies deſcribes that Orbit about the Sun, which we have hitherto ſaid, that the Earth deſcribed*; becauſe we looked the Action
1282 of the Moon; but *the Earth deſcribes an irregular Curve.*

1283 *Fig.* 4. *Plate* XXIV.] Let the Sun be at S; and the common Center of Gravity of the Moon Q, and the Earth at M, at the Time of the full Moon, be at F: After one whole Lunation, that is, the next full Moon, let that Center be at A; and let F D A be the Orbit which we call that of the Earth; but in which it is the Center of Gravity above-mentioned that does really move.

If this Lunation be divided into four equal Parts, after the firſt, the Center of Gravity will be at E, the Moon at P, and the Earth at L; after the ſecond Part of the Time, at New-Moon, the Center of Gravity will be at D, the Moon at R, and the Earth at I; in the following Quadrature, the Center of Gravity will be at B, the Moon at O, and the Earth at H. Laſtly, at Full-Moon the Center of Gravity being at A, the Moon will be at N, the Earth at G: All which follows from the Revolution of the Earth and Moon about their common Center of Gravity, whilſt it is carried in the Orbit about the Sun.

Therefore we ſee the Earth moves in the Curve M L I H G, which is twice inflected in each

each Lunation; which Curve alſo does not return into itſelf, becauſe the Inflections in the ſeveral Revolutions about the Sun do not coincide; for 12 Lunations, and a third Part of another, are performed every Year.

This Irregularity of the Motion of the Earth, 1284
which is deduced from the Laws of Nature, *is too ſmall to become ſenſible in Aſtronomical Obſervations*; wherefore we may without any Error ſay, that the Center of the Earth itſelf deſcribes the Orbit F D A; for M F, or D I, the greateſt Diſtance of the Earth from that Orbit, is about the 40th Part of the Diſtance I R, which Diſtance itſelf is not the 300th Part of the Diſtance F S.

In explaining what relates to the Moon, we alſo 1285
neglect the Conſideration of the Motion of the Earth about the common Center of Gravity above-mentioned, but we ſuppoſe it to revolve at the Diſtance of 60 *Semidiameters from the Center of the Earth*; becauſe, as we have before demonſtrated,* ſuch is the Di- *1253
ſtance at which, in its periodical Time, it could revolve about the Earth at Reſt, or be carried along in an Orbit in which it ſhould not be diſturbed by the Moon's Action. By this Method, the Moon's Irregularities will be much more eaſily diſcovered; for they are the ſame; as is evident, whether the Moon moves about the common Center of Gravity of the Moon and Earth, or about the Center of the Earth itſelf.

Plate XXV. *Fig.* 1.] Let S be the Sun; T the 1286
Earth; and the Orbit of the Moon A L B *l*; and laſt of all, let the Moon be at A in the Quadrature; it tends towards the Sun in the Direction A S, in the ſame Manner, and with the ſame Force that the Earth is carried towards S along T S, becauſe the Diſtances A S and T S are equal: This Force may be repreſented by T S or A S,

whereby the Moon endeavours to deſcend along A S, and is reſolved into two Forces, by drawing the Parallelogram A D S T; ſo that the Moon will endeavour to move in the Directions A D and A T, by Forces repreſented by thoſe
192 Lines.

By the Force which acts along A D, the Moon is carried with the ſame Celerity and the ſame Way of the Earth; by reaſon of the equal and parallel Lines T S and A D: Wherefore by this Motion, the Relation between the Moon and Earth is not changed; but the Force along A T
1287 conſpires with *the Gravity of the Moon towards the Earth*, and this Gravity *is encreaſed by the Action of the Sun, when the Moon is in the Quadratures; and the Augmentation or Addition is to the Gravity of the Earth towards the Sun, as* A T *the Moon's Diſtance from the Earth is to* T S, *the Earth's Diſtance from the Sun.*

1288 T S *the Earth's Diſtance from the Sun remaining the ſame, the* above-mentioned *Addition of Gravity encreaſes, and diminiſhes in the Ratio of the Line* A T, *the Diſtance of the Moon from the Earth.*

But this Diſtance of the Moon from the Earth A T, if it remains the ſame, and T S be encreaſed, then A T will be leſs in reſpect of A S: Therefore though there ſhould be no Change in the Force, whereby the Earth and Moon fall towards the Sun, the Addition will be leſs, and ſo much leſs as T S is greater; that is, it will be inverſly as T S; but the Force of Gravity does not remain the ſame, when T S is encreaſed, but is diminiſhed; wherefore alſo in that reſpect, the above-mentioned Addition is diminiſhed, and in the ſame Ratio with that Force of Gravity; therefore it is the inverſe Ratio of the Square of the
1208 Diſtance T S; if this Diminution be added to that above-mentioned, we ſee that the *Addition* of which

which we ſpeak, *follows the inverſe Ratio of the Cube of the Diſtance of the Earth from the Sun.* 1289

The Diſtance of the Earth from the Sun remaining the ſame, the Gravity of the Moon towards the Earth decreaſes more ſlowly in the Quadratures, than according to the inverſe Ratio of the Square of the Diſtance from the Center of the Earth; for if the Addition in that Caſe ſhould follow the inverſe Ratio of the Square of the Diſtance, as the Gravity from the Action of the Earth does,* this Ratio would not be diſturbed; but the Addition encreaſes when the Gravity itſelf is diminiſhed; wherefore the Addition, when the Diſtance is encreaſed, is always greater than is required, and conſequently the Diminution the leſs. 1290 *1208

This Addition is determined *in the mean Diſtances of the Moon from the Earth, and of the Earth from the Sun:* Let A T and T S be theſe mean Diſtances; the *Addition* required is to the Gravity of the Earth towards the Sun, as A T to T S*; the Gravity of the Earth towards the Sun, *is to the Gravity of the Moon towards the Earth* (becauſe theſe Bodies are retained by theſe Gravities in their Orbits) directly as T S to T A, and *inverſly as the Squares of the Periodical Times of the Earth about the Sun, and of the Moon about the Earth*:** Therefore the Addition required is to the Gravity of the Moon towards the Earth, in a Ratio compounded of theſe Ratio's; *that is*, the abovementioned inverſe Ratio of the periodical Times of the Earth and Moon, the other Ratio's deſtroying one another. Theſe Times are given, and their Squares are inverſly *as* 1 *to* 178,73. 1291 *1287 **237 1236

Now if the Moon be at L, [*Plate* XXV. *Fig.* 1.] in which Situation the Sun attracts the Moon and Earth in the ſame Line, but not equally; the Moon it draws with a greater Force, becauſe it is leſs diſtant from it: The Difference of 1292

thoſe Forces is the Force by which the Moon is drawn back from the Earth, and by which the Gravity of the Moon towards the Earth is diminiſhed.

The Forces whereby the Moon at L, and the Earth at T, tend towards the Sun, are to one
1208 another as the Squares of the Lines S T and S L: and the Difference of the Forces, that is, the diſturbing Force, is to the Force by which the Earth deſcends toward the Sun, as the Difference of thoſe Squares to the Square of the Line L S; that is, nearly as double L T to L S or T S; for
1293 theſe Lines do but very little differ from one another; and *the Difference of the Squares, whoſe Roots differ but little, is keeping the Proportion double that which is between the Roots.*

If therefore T S, as before, repreſents the Force whereby the Earth deſcends towards the Sun, L *l* will repreſent the diſturbing Force and diminiſhing Gravity, when A T repreſents the diſturb-
1286 ing Force in the Quadratures. Let the Moon be
1294 at *l*; it is again (together with the Earth) attracted by the Sun in the ſame Line; but the Earth, becauſe leſs diſtant, moves more ſwiftly to-
1208 wards the Sun; ſo that there is a Force which ſeparates the Earth from the Moon, namely, the Difference of the Forces which attract the Moon and the Earth; which Force always acts contrary to the Gravity of the Moon towards the Earth, and diminiſhes it, in the ſame Manner as has been demonſtrated from the greater Gravity of the Moon towards the Sun, ſuppoſing it at L. At *l* alſo the ſeparating Force ſcarce differs from the ſeparating Force at L; for this Force, as we have ſhewn, is proportional to the Difference of the Squares of the Lines T S and L S; and that (as appears by ſuch another Demonſtration) proportional to the

the Difference of the Squares of the Lines *l* S and T S; which Difference, by reaſon that L *l* is very ſmall in reſpect of T S, ſcarce differ among themſelves; ſo that the Force which diminiſhes the Moon's Gravity at *l*, is alſo repreſented by L*l*.

Yet *the Diſturbing Force is ſomething greater at the Conjunction* L, *than at the Oppoſition l*; for ſuppoſing the Differences between the Roots to be equal, the Squares, keeping the Proportion, will differ ſo much the more, the leſs they are; and ſo keeping the Proportion, the Forces differ more at L and T, than at T and *l* which alſo are leſs.* 1295 *1208

From this we conclude, that *the Force which diminiſhes the Gravity of the Moon in the Syzygies, is double that which encreaſes it in the Quadratures; namely, as* L*l to* A T. Wherefore in the Syzygies, the Gravity of the Moon from the Action of the Sun is diminiſhed by a Part, which is to the whole Gravity, *as* 1 *to* 89, 36; for in the Quadratures, the Addition of Gravity is to the Gravity, as 1 to 178,73.* 1296 *1291

In the Syzygies, the diſturbing Force follows the ſame Proportion with half added to it; that is, with the diſturbing Force in the Quadratures*; *it is* therefore *directly as the Diſtance of the Moon from the Earth,* and inverſly as the Cube of the Diſtance of the Earth from the Sun.* 1297 *1296 *1288 *1289

At the Syzygies the Gravity of the Moon towards the Earth, receding from its Center, is more diminiſhed, than according to the inverſe Ratio of the Square of the Diſtance from that Center; for it would be diminiſhed in that Ratio, if the Force to be taken away followed the ſame Ratio; but on the contrary, as it encreaſes when the Diſtance becomes greater,* the Diminution is always greater than in that Ratio. 1298 *1297

1299 *Plate* XXV. *Fig.* 1.] Laſtly, let the Moon be at F, in any intermediate Place between the Syzygy and Quadrature, it is drawn towards the Sun along FS; by which ſince it is leſs diſtant than the Earth T, it is attracted with more Force than the Earth: Let the Force, with which the Moon tends to the Sun, be to the Force, with which the Earth is carried towards it, as F M to T S, which alſo before has been made uſe of to expreſs the ſame Gravity of the Earth. Draw the Parallelogram F H M I, whoſe Diagonal is F M, and whoſe Side F H is parallel and equal to the Line T S. The Motion of the Moon towards the Sun is reſolved into two Motions, one along F H, the other along F I, and theſe Lines denote the Forces whereby the Moon endeavours
192 to move along them. The Motion along F H is common to the Moon and the Earth, which with an equal Force, and in a Line parallel to it, does alſo tend to the Sun: So that by this Motion of the Moon, the Situation of it, in reſpect of the Earth, will not be changed, and the diſturbing Force will be only the Motion along F I.

By reaſon of the immenſe Diſtance of the Sun, the Part M S of the Line M F is ſmall, in reſpect of the Whole, and the Angle F S T, where it is the greateſt, as A S T, is hardly more than the 6th Part of a Degree: Whence it follows, that the Lines M I and S N are very near one another, and that the Points I and N are ſcarce ſenſibly diſtant, and may without any ſenſible Error be confounded together; which Error, notwithſtanding how little ſoever it need be regarded, in Conſideration of one whole Revolution, is compenſated by a contrary Error when the Moon is at E. Therefore the diſturbing Force is expreſſed by F N.

It

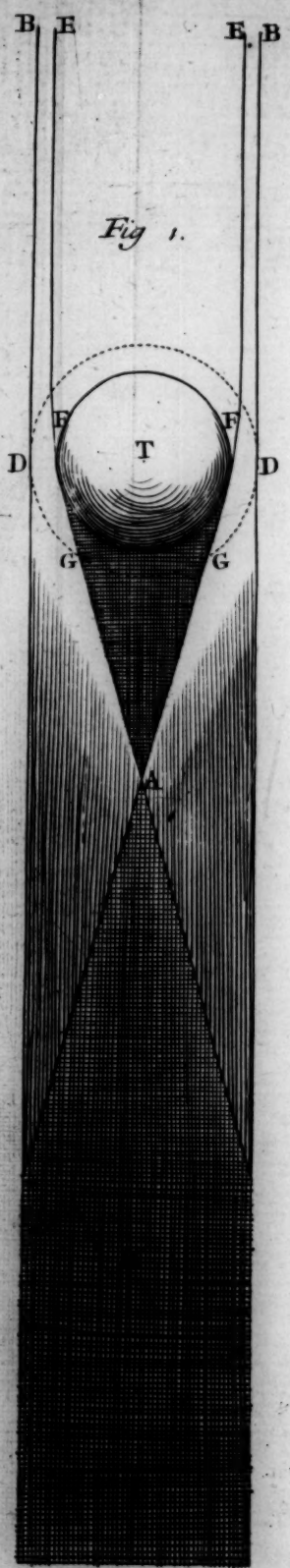


Fig 1.

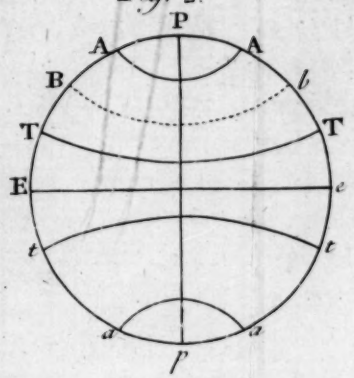


Fig. 2.

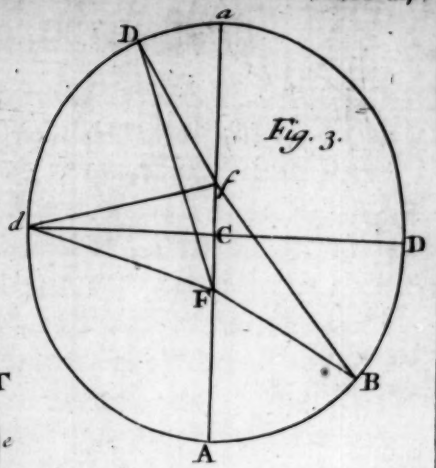


Fig. 3.

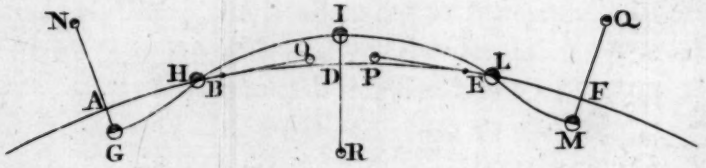


Fig. 4.



It is to be obſerved, when only the Part E F of the Line E S is conſidered, that it is to be looked upon as parallel to the Line L *l*, becauſe of the ſmall Angle which theſe Lines make. From the Point N, draw N Q perpendicular to the Line F T, continued if Need be, in which the Moon gravitates towards the Earth; and let the Rectangular Parallelogram E P N Q be drawn: Let us conceive the Force along F N reſolved into two others, acting in the Directions F Q and F P, and repreſented by theſe Lines:* By the Force along F Q, the Force of Gravity is diminiſhed, in the Caſe repreſented by this Figure; but it is encreaſed when the Point Q falls between F and T; but by the Force along F P, the Moon in its Orbit is drawn towards the next Syzygy L, and the Motion of the Moon is accelerated or retarded, according as this Force conſpires with, or acts contrary to the Moon's Motion. 1300 1301 *192

Near a Syzygy, the Gravity of the Moon is diminiſhed, and the Line F Q, which follows the Proportion of this Diminution, grows leſs, receding from the Syzygy till it vaniſhes, at the Diſtance of about 54 Degr. 44 Min. from it: At a greater Diſtance of the Moon from the Syzygy, Q falls in between F and T; and the Gravity of the Moon towards the Earth is encreaſed by the Sun's Action. The Force along F P vaniſhes in the Syzygy L; receding from it, it encreaſes quite to the Octant, which is the middle Point between the Syzygy and the Quadrature; and then it diminiſhes again till it vaniſhes quite at B.

Between B and *l*, or *l* and A, the diſturbing Motions are determined in the ſame Manner, as in A L B, the oppoſite inferior Part of the Orbit; at E and F, the Diminution of Gravity is equal, 1302

equal, and in that Poſition it is drawn in the Orbit with an equal Force towards the Syzygy *l*, with that with which at F it is impelled towards the Syzygy L.

1303 Hence it follows, *that in the Motion of the Moon from the Syzygy to the Quadrature*, between L and B, as alſo between *l* and A; *the Gravity of the Moon towards the Earth is continually encreaſed,*

1304 *and the Moon is continually retarded in its Motion.* But *in the Motion from the Quadrature to the Syzygy*, between B and *l*, as alſo between A and L, *every Moment the Moon's Gravity is diminiſhed, and its Motion in its Orbit is accelerated.*

You may determine the Forces upon which theſe Effects depend, by comparing them with the known Force, whereby Gravity is encreaſed in the

1291 Quadratures, and which is repreſented by the Moon's Diſtance from the Center of the Earth.

1305. The Lines M I, H F, S T, are equal by Conſtruction; therefore when the Points I and N are confounded, M N is equal to S T, and M S is equal to N T. The Lines M F and S T repreſent the Forces, whereby the Moon at F and the Earth at T are carried towards the Sun S; therefore they are as the Square of the Line T S

1208 to the Square of the Line F S; wherefore as F G is the Difference of thoſe Lines, F M and T S differ from one another double the Line

2293 G F, and adding G F to the Line F M, the Difference between G M and T S, that is, M S will be triple the Line F G; and therefore this is alſo the Quantity of the Line N T: Now as F E

1300 is double F G; therefore N T will be to F E as Three to Two.

Let F T be continued, if Need be, and from E draw E V perpendicular to it; the Triangles E V F and N Q T, which are rectangular, will be ſimilar, by reaſon of the alternate Angles

V F E

V F E and Q T N :* Therefore N T is to F E, *1300
that is, Three is to Two, as N Q, equal to F P, is to E V ; which therefore is proportional to two third Parts of the Force, which is expreſſed by F P ; but E V is the Sine of the Angle E T V at the Center, which is double the Angle E F V at the Circumference, equal to the Angle F T L, which is the Diſtance of the Moon from the Syzygy. Therefore, *as the Radius* T A, or T E, 1306
is to a Sine and an half of double the Diſtance of the Moon from the Syzygy, namely, F P, *ſo the Addition of Gravity in the Quadratures* (which is expreſſed by the Radius T A) *is to the Force which accelerates or retards the Moon in its Orbit.*

The Computation of this Diminution of Gravity, and of its Encreaſe at a leſs Diſtance from the Quadratures, is deduced from the ſame Principles.

This Diminution is repreſented by the Line F Q, which is equal to Q T, *minus* the Radius ; but from the Conſideration of the Triangles above-mentioned, V F taken once and an half is equal to Q T ; therefore V T and an half, with half the Radius added to it, expreſſes the required Diminution of Gravity ; and *the Radius is to the* 1307
Sum or Difference of once and a half the Co-ſine of double the Diſtance of the Moon from the Syzygy and half the Radius : As the Addition of Gravity in the Quadratures, to the Diminution or Encreaſe of Gravity in that Situation of the Moon, concerning which the Computation is made.

We make uſe of the Difference of the Co-ſine from half the Radius, when the Angle, whoſe the Co-ſine is, is greater than a right Angle ; becauſe in that Caſe we make uſe of the Co-ſine of the Complement of the Angle to two right Angles : When in this ſame Caſe the Co-ſine and a half, which we make uſe of, is greater

greater than half the Radius, the Quantity found is to be added; that is, encreaſes the Gravity, which obtains every where between the Quadrature, and 35 Degr. 16 Min. from it.

1308 *Theſe Forces, whatever is the Figure of the Moon's Orbit, are exactly determined*; for they are compared with the Addition of Gravity in the Quadratures, ſuppoſing the Moon in the Quadrature to be at the ſame Diſtance from the Earth, at which it really is in the Place which is conſidered; but this Addition is diſcovered in every *1291 1288, Caſe.*

1289, Though it be foreign to the Purpoſe of this Work, to give a Computation of the Moon's Motion, I thought it neceſſary to explain in a few Words, what is the Method whereby to diſcover the Forces that govern the Moon; becauſe the more exactly we know the Forces, the more eaſily we ſhall conceive their general Effect.

Now to examine the Moon's Motion, we muſt ſingly conſider its ſeveral Irregularities; which to do without Confuſion, we muſt remove ſeveral Irregularities, and conceive the Moon as moving in a Circle about the Earth, in which Curve it is plain, that it can be retain-*241, ed by Gravity.* This Motion is diſturbed by 1208 the Action of the Sun, *and the Orbit is more con-*1309 *vex in the Quadratures than in the Syzygies.* The Convexity of a Curve, which a Body deſcribes by a central Force, is ſo much the greater, as the central Force does more ſtrongly every Moment turn the Body out of the Way; it is alſo the greater, the more ſlowly the Body moves; becauſe the central Force, acting the longer, has a greater Effect in inflecting the Way of the Body. From contrary Cauſes the Convexity of the Curve is diminiſhed. Both concur in encreaſing the

the Convexity of the Orbit in the Quadratures, * and diminiſhing it in the Syzgies.* *1303 *1304

From this it follows, that the circular Figure of the Moon's Orbit is changed into an Oval, whoſe greater Axis goes through the Quadratures; ſo that the more convex Parts are in the Quadratures. Wherefore *the Moon is leſs diſtant from the Earth at the Syzygies, and more at the Quadratures*, and it is no Wonder that the Moon comes towards the Earth, when its Gravity is diminiſhed; becauſe the Acceſs is not the immediate Effect of this Diminution, but of the Inflexion of the Orbit towards the Quadratures. 1310

The Motion of the Moon, taking away the Action of the Sun, is not in a Circle, but in an Ellipſe, one of whoſe Foci coincides with the Center of the Earth; * for the Orbit of the Moon is Excentric, and it is retained in it by the Force of Gravity. *967, 241, 1180

Therefore what has been demonſtrated cannot be exactly applied to the Moon's Motion; for as the Forces, which generate the Deviations explained, do really act upon the Moon, the Ellipſe, which the Moon would deſcribe if the Sun was taken away, is changed, *and cæteris paribus, the Propoſitions of* N° 1309, 1310, *may be applied to the Moon's Motion.* 1311

In the Quadratures and Syzygies, the diſturbing Force acts in the ſame Line as the Force of Gravity towards the Earth;* therefore the Force which continually acts upon the Moon, and retains it in its Orbit, is directed towards the Center of the Earth, and *the Moon deſcribes Area's by Lines drawn to the Center, of the Earth proportional to the Times.** 1312 *1286 1292, 1294 *215

Plate XXV. *Fig.* 1.] *In other Points of the Orbit*, as F, beſides the Force which acts in the Line F T, there is alſo another, whoſe Direction 1313

1301 ction is perpendicular to F T, * which is here repreſented by F P: The Direction of the Force compounded of both, is directed ſometimes ſidewiſe to the Line F T, and does not tend to the
190 Center of the Earth;* wherefore *the Area's, by Lines drawn to the Center of the Earth, are not ex-*
226 *actly proportional to the Times.** In the Octants, F P is the greateſt of all; and the Force, which is repreſented by that Line, is to the Gravity of the Moon towards the Earth, in that Point, in the Mean Diſtances of the Sun and Moon, as 1 to
1306 119,49.* Wherefore the Direction of the Force,
1307 compounded of the Actions of the Sun and Earth upon the Moon, makes an Angle of above half a Degree with the Line F T.

The Motion of the Moon is ſubject to ſeveral other Irregularities; ſo that it deſcribes a Curve wholly irregular; which *Aſtronomers*, in order to ſubject it to the moſt exact Computations
1314 that can be made, do *reduce to an Ellipſe which they conceive to be agitated by various Motions, and alſo to be changeable, leſt the Moon ſhould go out of it.*

In reſpect to central Forces we have obſerved, that a Body does not deſcribe an Ellipſe, if the central Force, by which it is retained in its Orbit, decreaſes in any other Ratio than the Inverſe Ratio of the Square of the Diſtance; but that the Curve may be often reduced to a moveable El-
243 lipſe: * Concerning which it is to be obſerv-
1315 ed, that *the Ellipſe*, in that Motion, *turns about*
1316 *one of its Foci, and the Motion of the Ellipſe is directed the ſame Way as the Motion of the Body in it, when the central Force decreaſes faſter than in the Inverſe Ratio of the Square of the Diſtance.* But *if the central Force decreaſes ſlower as you recede from the Center, the Ellipſe is carried the contrary Way*; as theſe Things may be demonſtrated Mathematically.

Hence

Hence it follows, the Orbit of the Moon cannot be referred to an Elliptic Orbit, unleſs you ſuppoſe it agitated by four Motions every Revolution; that is, unleſs the Line of the Apſides, which goes through the Center of the Earth, goes forwards twice, and backwards twice.

*The Apſides of the Moon go forward when the Moon is in the Syzygies,** or rather whilſt the Moon moves between the Points, which are 54 Degr. 44 Min. diſtant from them. * *In the Quadratures*, and between the Points diſtant from them 35 Degr. 16 Min. *The Apſides go backwards*, that is, move in *Antecedentia*.* 1317 *1315 1298 *1307 1318 *1316

The Forces, upon which *the Progreſs* and Regreſs *of the Apſides* depend, are the Forces which diſturb the Motion of the Moon, which have been before explained; therefore, ſince the diſturbing Force in the Syzygies, is double the diſturbing Force in the Quadratures;* the Progreſs, *conſidering one entire Revolution of the Moon, exceeds the Regreſs, cæteris paribus.* 1290 1307 1319 *1296

In a Circle whoſe Center is in the Center of the Forces, the Diminution of the Force, in receding from the Center, produces no Effect; becauſe in ſuch a Line the Body does not recede from the Center; therefore the Effect of this Diminution is ſo much the greater, as the Curve deſcribed by the Body differs more from ſuch a Circle.

In an Elliptic Orbit, one of whoſe Foci coincides with the Center of the Forces, the Curvature in *the Apſides* differs moſt of all from ſuch a Circle, and *the Effect of the Diminution of the Force, in receding from the Center of the Forces, is the greateſt of all. If this Orbit is but a little Excentric at the Ends of the leſſer Axis*, the Ellipſe differs very little from the Circle above-mentioned, and *the Effect of the Diminution is the leaſt of all.* 1320 1321

The

1322 The *Progreſs and Regreſs of the Apſides* depend upon the Proportion, according to which the Force of Gravity decreaſes, receding from the
1315 Center of the Earth; it *is* therefore *the Effect of*
1316 *the Diminution of the Central Force.*

1323 *Plate* XXV. *Fig.* 2.] This Motion of the Apſides, which we have explained, undergoes ſeveral Changes; *the Apſides go forward faſteſt of all in a Revolution of the Moon, ſuppoſing the Line*
*1317 *of the Apſides in the Quadratures;* * *and in that*
1322 *very Caſe, they go back the ſloweſt of all in the ſame*
1320 *Revolution,* * becauſe, by reaſon of the ſame Ex-
*1318 centricity of the Moon, the Quadratures are but
1321 very little diſtant from the Ends of the leſſer
1322 Axis of the Orbit.

1324 *Suppoſing the Line of the Apſides to be in the Qua-*
*1317 *dratures, the Apſides are carried in* Conſequentia,
1322 *the leaſt of all in the Syzygies;* * *but they return the*
1321 *ſwifteſt in the Quadratures;* * *and in this Caſe,*
*1318 *in one entire Revolution of the Moon, the Regreſs*
*1322 *exceeds the Progreſs.*
1320

1325 Whilſt the Earth is carried along in its Orbit, the Line of the Apſides does ſucceſſively go through all Situations in reſpect of the Sun; wherefore, *conſidering a great many Revolutions of the Moon*
*1319 *taken together, the Apſides go forwards;* * and it is plain from Obſervations, that in the Space of about eight Years, the Line of the Apſides performs one entire Revolution.

We have alſo ſaid that the Excentricity of the Orbit is not conſtant.

1326 *The Excentricity of a Body is encreaſed, if the central Force,* the Diminution being continued, *decreaſes faſter than before,* whilſt the Body is carried from the lower to the upper Apſis; for then it is every Moment leſs attracted, than if the Force did not decreaſe; and therefore it recedes the more. The Excentricity of the Orbit is alſo thereby encreaſed, in the ſame Caſe, in the

the Motion from the upper to the lower Apſis, becauſe in this Caſe, coming towards the Center, the Force encreaſes ſo much the faſter, as the Body deſcends more towards the Center; ſo that in each Caſe, the Difference between the greateſt and leaſt Diſtance from the Center of the Forces, may become greater, and the Excentricity be thereby encreaſed. By the ſame 1327
Reaſoning it appears, that *the Excentricity is diminiſhed, when the Central Force* is encreaſed, in the Motion of the Body from the lower to the upper Apſis; and likewiſe when that Force is diminiſhed in the Motion from the upper Apſis to the lower; that is, when *it decreaſes more ſlowly than before, in the receding from the Center.*

Applying this to the Moon's Motion, it ap- 1328
pears, that *the Excentricity of the Orbit, every Revolution, undergoes various Changes. That it is* 1329
the greateſt of all, when the Line of the Apſides is in the Syzygies; becauſe the Forces in the Apſides, being compared, do decreaſe faſter than in an inverſe Ratio of the Square of the Diſtance,* *1298
whence this Addition follows,* which prevails *1326
in this Poſition:* But *the Orbit is the leaſt Ex-* *1320
centric of all, when the Line of the Apſides is in the Quadratures, the Diminution of the Excentricity prevailing.* *1290

We have ſaid that the Moon moves in a Plane 1327
inclined to the Plane of the Ecliptic; that the 1321
Line of the Nodes is carried round in *Antecedentia*;* and that the Inclination of the Orbit is *970
not conſtant;* theſe Effects are alſo deduced from *969
the Action of the Sun upon the Moon.

By reaſon of the ſmall Inclination of the Moon's Orbit, the Forces which we have hitherto conſidered acting in the Plane of the Ecliptic, not regarding the Inclination of the Orbit, may (without any ſenſible Error) be referred to the Plane

of the Orbit; and the Moon in it is ſubject to the
1330 Motions before explained: But *there is a Force which removes the Moon from the Plane of the Or-*
*1314 *bit*;* ſo that we muſt conceive that Plane to be agitated, otherwiſe the Moon would go out of the Orbit.

1331 *Plate* XXV. *Fig.* 1.] Let the Moon be at F; if we attend to what has been ſaid above con-
1299 cerning the Actions of the Sun, it is plain, that the Plane of the Parallelogram FHMI goes through the Line T S, which joins the Centers of the Earth and Sun; and therefore it is in the Plane of the Ecliptic; ſo that the Point N, to which is directed the Force FN, diſturbing on account of the Action of the Sun, is in that Plane.

1332 *Plate* XXV. *Fig.* 4.] Let the ſame Force be repreſented by FI; at F let FR be raiſed perpendicular to the Plane of the Orbit; and imagine the Parallelogram FRI*i*, whoſe Side F*i* is in the Plane of the Orbit, and whoſe Diagonal is FI; the diſturbing Force along FI is reſolved into two, in the Directions FR and F*i* which
192 theſe Lines repreſent, and of which this laſt acts in the Plane of the Orbit: So that we muſt refer to this what relates to the diſturbing Force, of which we have treated in N° 1299; for the Lines F*i* and FI ſcarce differ, and the Plane of the Parallelogram FRI*i* is perpendicular to the Plane of the Moon's Orbit.

1333 The Line FR muſt be determined, which repreſents the Force that acts perpendicular to the Plane of the Orbit, and removes the Moon from that Plane: Now the Relation of the Line FR or I*i*, to the Radius ET, is the Ratio of the diſturbing Force, which is ſpoken of here,
1286 to the Encreaſe of Gravity in the Quadratures.

In

In the Caſe of this Figure, in which the Line of Nodes N*n* is in the Quadratures, we find out F R; becauſe I T (which is N T of *Fig.* 1.) is given,* and becauſe I T is to *Ii*, or to F R, as the Radius to the Sine of the Inclination of the Orbit. 1334 *1325

But in every Caſe the Force muſt be determined which drives the Moon out of the Plane; let us therefore ſuppoſe the Line of Nodes carried to the Situation M *m*, whereby, every thing elſe remaining as before, I *i* is changed. To M *m* continued, if Need be, let *i* X and I X be drawn perpendicular, which make an Angle equal to the Inclination of the Plane of the Orbit. 1335

The Ratio between E T and I*i*; that is, *the Ratio between the Addition of Gravity in the Quadratures, and the Force*, which we ſeek, *which removes the Moon out of its Orbit*, is compounded of the Ratio's of the Line E T to T I, of the Line T I to I X, and laſtly of the Line I X to I *i*. The firſt is the Ratio between the Radius and three Times the Sine of the Diſtance of the Moon from the Quadrature;* the ſecond is the Ratio of the Radius to the Sine of the Angle I T X, that is, of the Diſtance of the Node from the Syzygy. *Laſtly*, the third is the Ratio of the Radius to the Sine of the Inclination of the Orbit: And the Ratio, compounded of theſe, *is the Ratio of the Cube of the Radius to three times the Product of the Sines of the Diſtances of the Moon from the Quadrature, and of the Node from the Syzygy, as alſo of the Inclination of the Plane.* To this Force is alſo to be referred N° 1308. 1336 *1305

This Force vaniſhes in the Quadratures, becauſe the Point I coincides with the Point T, which is the Center of the Earth, and the Line I*i* vaniſhes; the Lines F I and F*i* concurring in the Plane of the Orbit, which alſo follows from the Computation above-mentioned;* the Sine of 1337 *1136

the Diſtance of the Moon from the Quadrature vaniſhing, and conſequently, the whole Product which is multiplied by that Sine.

1331 That ſame Product vaniſhes alſo, and with it *the Force* which it repreſents, when the Sine of the Diſtance of the Node from the Syzygy *vaniſhes*, that is, *ſuppoſing the Line of the Nodes in the Syzygies:* It is alſo deduced from this, that the Line of Nodes N *n* (*Plate* XXV. *Fig.* 5.) continued goes through the Sun, wherefore the Sun is in the Plane of the Orbit itſelf, and therefore cannot draw the Moon but in that Plane.

1339 *The Force* alſo, *which we examine, is increaſed as the Moon advances towards the Syzygy, and as* *1336 *the Node recedes from it.**

1340 *Plate* XXV. *Fig.* 6.] Let P *p* be the Plane of the Ecliptic, P A the Orbit of the Moon; when the Moon is come to A, that is, is receded a little from the Node, it is removed out of the Plane of the Orbit, and in the ſecond Moment it is not carried along A B (the Continuation of the Orbit P A) but along A *b*; becauſe it comes towards the Plane of the Ecliptic along B *b*; therefore it is moved as if it came from a more di-

1341 ſtant Node *p*. Whence it appears, that *the Nodes go backward, whilſt the Moon moves in its Orbit*, as long as it recedes from the Node: The Nodes alſo go back, whilſt the Moon is going to the oppoſite Node; becauſe as the Moon is continually driven out of its Orbit towards the Plane of the Ecliptic, it is continually directed to a Point leſs diſtant, and comes ſooner to the Node, than if, not being agitated by ſuch a Motion, it had continued in Motion with the ſame Celerity.

1342 *Conſidering one entire Revolution of the Moon* cæteris paribus, *the Nodes move in* Antecedentia *1339 *ſwifteſt of all, when the Moon is in the Syzygies,* then ſlower and ſlower, till they are at Reſt, when *1337 *the Moon is in the Quadratures.* Whilſt

Whilſt the Earth is carried round the Sun (even when we do not attend to the above-mentioned Motion of the Nodes) *the Line of Nodes* 1343
does ſucceſſively acquire all poſſible Situations in reſpect of the Sun; and *every Year goes twice through the Syzygies, and twice thro' the Quadratures.*

If now *we conſider ſeveral Revolutions of the* 1344
*Moon, the Nodes in one whole Revolution go back very faſt, the Nodes being in the Quadratures;** *1339
*then ſlower, till they come to reſt, when the Line of Nodes is in the Syzygies.** *1338

By the ſame Force with which the Nodes are 1345
moved, *the Inclination of the Orbit* is alſo changed; it *is increaſed as the Moon recedes from the Node; and diminiſhed as it comes to the Node.*

Plate XXV. *Fig.* 6.] For the Angle *bp*L is 1346
leſs than the Angle A P L, and for the ſame Cauſe it is continually diminiſhed, and the Inclination becomes greater; but when the Moon is come to the greateſt Diſtance from the Plane of the Ecliptic, and is going towards the oppoſite Node, the Direction of the Moon is continually inflected towards the Plane of the Ecliptic, and leſs inclined to it than if it continued in Motion in its Orbit: Let N *pn* be the Plane of the Ecliptic; the Curve N *n* the Orbit of the Moon; by the Force whereby the Moon is continually removed out of it, the Way of the Moon is changed, and it goes in the Curve N *p*, which is more inclined to N *pn* at N than at *p*; ſo that we muſt conceive the Inclination of the Plane of the Orbit to be twice changed;* whilſt the Moon *1314
moves from one Node to the other; therefore this happens four times *in each Revolution of the Moon,* 1347
it is twice diminiſhed, and twice again encreaſed.

Plate XXV. *Fig.* 4.] *Suppoſing the Nodes* N *n,* 1348
to be *in the Quadratures,* the Forces which *in one Revolution* encreaſe *the Inclination,* and diminiſh it, are equal to one another; for by reaſon of the

equal Diſtance of each Node from the Syzygies, the Forces that change the Inclination at N D and *n* E are equal to the Forces in the correſpon-
*1336 dent Points in the Arcs D *n* and E N :* By the former the Inclination is encreaſed, by the latter
1345 it is diminiſhed ; the Diminution of the Angle of Inclination, on account of the firſt, is reſtored by the Action of the ſecond, and here it *is not*
*1343 *changed.* In the Motion above-mentioned* of the Line of Nodes in reſpect to the Sun, which depends upon the parallel Situation of this Line, the Node N is carried to the Syzygy E. When (*for Ex.*) the Line of Nodes is come to the Situation M *m*, the Moon in its Receſs from the Nodes goes through the Quadratures N *n*, in which the Force which changes the Inclination
1337 vaniſhes, and near which it is the leaſt of all :*
*1336 but in coming towards the Nodes, the Moon is every where diſtant from the Quadratures, and
1336 a greater Force acts upon it ; therefore *con-*
1349 *ſidering one entire Revolution*, the Encreaſe of the
1345 Angle of Inclination exceeds its Diminution ; that is, that Angle is encreaſed, or which is the ſame, *the Inclination is diminiſhed*; which obtains every where *in the Motion of the Nodes from the Quadratures to the Syzygies.*

1350 *When the Nodes are come to the Syzygies, the In-*
1351 *clination of the Plane of the Orbit is the leaſt of all*; for *in the Motion of the Nodes from the Syzygies to the Quadratures*, the Plane of the Orbit is continually more and more inclined; for in that Caſe as the Moon goes to the Node, it paſſes through the Quadratures ; in its Receſs from them the Moon is diſtant from the Quadratures, and *in one whole Revolution of the Moon*, the Force which
*1337 encreaſes the Inclination * exceeds that which
1345 diminiſhes it ; therefore *the Inclination is en-*
1352 *creaſed* ; and *it is the greateſt of all when the Nodes are in the Quadratures*, where the Diminution of

the

the Angle made by the Plane of the Orbit with the Plane of the Ecliptic is terminated.* *1349

All the Errors in the Moon's Motion, that we have explained, *are ſomething greater in the Conjunction than in the Oppoſition.** 1353 *1295

All the diſturbing Forces are determined by diſcovering their Relation with the Addition of Gravity in the Quadratures;* for which Reaſon they all undergo the ſame Changes as that Addition does; that is, they *are inverſly, as the Cube of the Diſtance of the Sun from the Earth,* *which when it remains the ſame, they are as the Diſtance of the Moon from the Earth.** *Conſidering all the diſturbing Forces together, the Diminution of Gravity prevails*;* which follows immediately from the Progreſs of the Apſides; for it appears from thence, that conſidering ſeveral Revolutions together, the Effect of the Diminution of Gravity exceeds the Effect of the Encreaſe of it.* 1354 *1306 1307 1336 *1289 *1288 1355 *1296 *970 1325 *1317 1318

Therefore *the Motion of the Moon being conſidered in general, the Gravity of the Moon towards the Earth is diminiſhed, coming near the Sun*;* therefore when it is leſs attracted by the Earth, it recedes more from it than it would recede, if there was no ſuch Diminution of Gravity: Therefore in that Caſe the Moon's Diſtance is encreaſed, as alſo *the Periodical Time*;* and that Time *is the greateſt, as alſo the Diſtance of the Moon (cæteris paribus) the greateſt, when the Earth is in the Perihelion,** becauſe then it is leaſt diſtant from the Sun. 1356 *1355 1354 1357 *224 *1354

CHAP. XVII.

Concerning the Figures of the Planets.

IF we conſider the Figures of the Planets, we ſhall find that they have ſuch Figures, which follow from theſe very Laws by which

the Syſtem is governed; which is very agreeable to that admirable Order which we obſerve every where, that no Forces act upon the Planets to
1358 deſtroy them; that is, that *the Figure of a Planet, whether it be a Primary or Secondary Planet, is ſuch as it would acquire, if it wholly conſiſted of fluid Matter*; which agrees with the Phænomena.

1359 Whence it follows, that *all the Primary and Secondary Planets are Spherical*; for they conſiſt of a Matter whoſe Particles gravitate towards one
1206 another; from which mutual Attraction a Sphe-
1207 rical Figure is generated in the ſame Manner, as a Drop becomes round from another Sort of At-
34 traction of the Parts.

1360 *This Spherical Figure of the Planets is not changed from their Motion round the Sun, or from the Motion of the Secondary Planets about their Primary ones*; becauſe all the Particles are carried by the ſame Motion: But this Figure undergoes ſome Change by the Motion round the Axis, and ſo much the greater as this Motion is ſwifter.

1361 *Plate* XXV. *Fig.* 7.] Let P P be the Axis of a *Planet*; E *e* the Diameter of the Æquator perpendicular to the Axis; let there be a Canal P C E filled with a Liquid; this Fluid will deſcend by its Gravity in both Legs towards C, and will not be at reſt, till the Preſſure in both Legs be equal. If the Planet be at reſt, the
1359 Height of the Fluid in both Legs will be equal: but if the Planet be moved about its Axis P *p*, all the Liquid in the Leg C E will endeavour to
217 recede from the Center by its centrifugal Force,
223 which Force acts contrary to Gravity, and therefore diminiſhes the Gravity; ſo that there is no *Æquilibrium* till C E exceeds C P. Now if the Canal be taken away, the lateral Preſſure of the Fluid, of which the Planet conſiſts, does not change the Gravity towards C, nor the Difference

ference between the Heights of the Columns C E, C P;* therefore the Planet is every where higher in the Æquator than in the Poles, and *acquires, by its Motion round its Axis, the Figure of a Spheroid depreſſed in its Poles*; for the Elevation is continually diminiſhed as you go towards the Pole, becauſe the centrifugal Force is diminiſhed by reaſon of the Diminution of the Diſtance from the Axis.* *280 1362 *232

If what has been demonſtrated be compared with the Phænomena, it will appear why all the Bodies in our Syſtem are ſpherical;* but that this Figure is not exact, but a little changed by their Motion round their Axis,* though this cannot be obſerved in moſt of them, may be deduced from Obſervations made upon *Jupiter* and the Earth. *Aſtronomers have obſerved that the Axis of* Jupiter *is ſhorter than its Æquatorial Diameter*; although this Planet be the greateſt of all the Planets, it is moved the ſwifteſt about its Axis;* and therefore this Difference may be obſerved. *924 *1362 1363 *962

The Elevation of the Earth at the Æquator is determined by us, although perhaps to the Inhabitants of the other Planets, if there are any, it may not be more ſenſible than the Elevations on *Mars* and *Venus* are to us, which are ſo ſmall that we cannot perceive them. 1364

Suppoſe the Earth to be fluid, it will acquire the aforeſaid ſpheroidical Figure:* If the Parts cohere towards the Center, the Poſition of the other Parts will not be changed thereby, nor will it be changed, if in ſome Places the Parts cohere together quite to the Surface; ſo that the Surface of the Sea muſt neceſſarily acquire a ſpheroidical Figure depreſſed at the Poles. But ſince the Shores are every where but a little elevated above the Surface of the Sea, it is certain that the Continent acquires the ſame Figure. 1365 *1362

Now

Now to meaſure this Elevation, that is, how much the Diameter of the Æquator of the Earth is longer than the Axis, we muſt conſider its Motion round its Axis in the Space of 23 Hours,
960 56 Min. 4 Sec. and ſuppoſing the Earth homogeneous, the Computation will be made in the following Manner.

1366 The Periphery of the Earth is 128,202,185 *Rhynland* Feet; therefore in one Second of Time, a Point of the Æquator goes through 1488 Feet; the verſed Sine of which Arc is 0,054, a Space which could be gone through by a Body in ſuch a Time by the centrifugal Force.

By a Gravity, a Body, in one Second, as we have ſhewn before, falls through 15,607 *Rhynland* Feet; but theſe Experiments were made at the Diſtance of 48 Degr. from the Æquator E *e* (*Plate* XXV. *Fig.* 7.) at the Point A, the centrifugal Force at E is to the centrifugal Force at A, as C E to C A, for theſe Lines are very little dif-
232 ferent at A B: Let this centrifugal Force be A *b*; having drawn the Perpendicular *b a* to C A continued, let the Force through A *b* be reſolved into two other Forces directed along A *a*
*192 and *a b*;* the Gravity is diminiſhed only by the former, and A *b* is to the Force diminiſhing it, as C A to A B, by reaſon of the ſimilar rectangular Triangles A *b a* and A B C, which have their oppoſite vertical Angles equal at A; therefore the centrifugal Force at the Æquator, with which a Body in one Second goes through 0,054; is to the Force which diminiſhes the Gravity at A, in a duplicate Proportion of the Radius A C to A B, which is the Co-ſine of the Latitude A E of 48 Degr. So that from this diminiſhing Force the Body in one Second goes through 0,0243; wherefore, if the Earth was at reſt, in falling it would not go through 15,607 Feet, but 15,632;

with

with which Gravity a Body falls under the Poles, becauſe theſe Points are not moved. At the Æquator, by the centrifugal Force, a Body goes through 0, 054. and falls as much in the ſame Time from the Height of 15, 578 Feet; whence it appears that the Gravity under the Poles is, to the Gravity under the Æquator, as 289 to 288.

If *Fig.* 7. repreſents the Figure of the Earth, the Weight of a Column of Liquid C E will be to the Weight of a Column of Liquid C A, the Earth being at reſt, as 289 to 288; for otherwiſe, the Earth moving, there will not be an *Æquilibrium*; becauſe $\frac{1}{289}$ of the Column C E is ſuſtained by the centrifugal Force; for the centrifugal Force decreaſes as you come towards the Center, in the Ratio of the Diſtance,* in which Ratio alſo the Gravity decreaſes;* ſo that in all the Points of the Column, the ſame Part of the Weight is ſuſtained, as towards the Surface. *232 *1233

Whence we deduce, that *the Height* C P *at the Pole is, to the Height* E C *at the Æquator, as* 229 *to* 230; for ſuppoſing this Ratio between the Axis and the Æquatorial Diameter, if a Computation be made of the Gravities in the Places P and E, the Earth being at reſt, they are found to be to one another, as 1121, 71. to 1120, 71; which Ratio obtains every where in correſpondent Points, that is, which are diſtant from the Center as C P to P E; becauſe in both Legs the Gravity decreaſes in Proportion to the Diſtance from the Center.* You have the Weight by multiplying the Quantity of Matter by the Gravity; for the Weight encreaſes in a Ratio of both: By multiplying 1121, 71. by 229, and 1120, 71. by 230. the Products are to one another as 288 to 289; which is the Ratio of the Weights before diſcovered. The mean Diameter 1367 *1233

of

976 of the Earth is 3,400,669 Perches, therefore the Axis P P is 3,393,261, and the Æquatorial Diameter E *e* is 3,408,078 Perches, which exceeds
1368 the Axis by 14,817 Perches (*viz.*) $\frac{1}{230}$, and *the Æquator is more elevated by* 7408,5.

1369 In this Computation, as we have ſaid, we have looked upon the Earth as homogeneous; but if it be more denſe towards the Center, the Matter which is added to it may be looked upon as a ſeparate Body, from whoſe Center the Points P and E are unequally diſtant, and towards which therefore the Bodies P and E have a dif-
1226 ferent Gravity; and the Difference is ſo much the greater as theſe Differences are greater; and it will be alſo ſo much the greater in reſpect of the whole Gravity, as the Quantity of Matter which is added, or which is the ſame, as the Denſity is greater towards the Center.

It is plain that the Forces of Gravity, at the Poles and the Æquator, differ from one another more than $\frac{1}{289}$ Part, by comparing together Experiments made at ſeveral Diſtances from the Æquator, by the Help of Pendulums, by which the Forces of Gravity may be compared together,
164 as we have ſhewn; and which Difference is truly
165 nearly double that which is found by Computa-
1370 tion; whence it follows, that *the Elevation of the Æquator is nearly double that which we have de-*
*1368 *termined to be* 7408, 5 *Perches.**

Now if we conſider the ſpheroidical Figure
1371 of the Earth, we ſhall ſee that *heavy Bodies do not tend directly to the Earth's Center*, unleſs at the Poles and the Æquator, *but every where perpendicularly to the Surface* of the Spheroid; for a Liquid will not be at reſt, unleſs its upper Surface forms a right Angle with the Direction of heavy
272 Bodies; and the Figure of a Spheroid is formed by the Surface of a quieſcent Fluid. We alſo

alſo deduce this Direction of heavy Bodies from the centrifugal Force (*Plate* XXV. *Fig.* 7.) The Body A, by its Gravity, tends towards C, and is carried by its centrifugal Force along A *b*: This Force at the Point A is to the Gravity along A C, as 1 to 430, 8. having formed a Parallelogram with the Sides A *c* and A *b*, ſuppoſing theſe to one another, as 430, 8. to 1, the Diagonal will ſhew the Direction of heavy Bodies,* forming a ſmall Angle with the Line A C. The Force along A *b* encreaſes as you go towards the Æquator, whereby this Angle is encreaſed, but is diminiſhed by the Encreaſe of the Angle C A *b*; ſo that in the Æquator, where the centrifugal Force is greateſt, the Direction of heavy Bodies coincides with E C; at the Pole it coincides with P C; becauſe there is no centrifugal Force there. 1372 *190

In this ſpheroidical Figure, *the Latitude of the Place is determined by an Angle*, as A C E, *which is made with the Æquator, by a Line drawn from the Place of the Center.* Dividing this whole Arc P A E, by this Method, into 90 Parts, that is, into Degrees, it will eaſily appear, that *going towards the Poles, the Degrees are encreaſed on the Surface*; but this Difference is ſo very ſmall, that in meaſuring Degrees that are not very diſtant, it cannot be diſcovered; becauſe the Error, ariſing from the Make and Uſe of the Inſtruments, exceeds this Difference. Whence Degrees meaſured at the South and North of *France*, as alſo in *England*, differ little from one another, and the middle one is the leaſt of all; wherefore *nothing can be concluded concerning the Earth's Figure from* theſe Meaſures. 1373 1374 1375

CHAP.

CHAP. XVIII.

The Phyſical Explanation of the Motion of the Axis of the Earth.

THAT the Nodes of the Moon go back,
*1341 that is, are moved in *Antecedentia*,* and that the Inclination of its Orbit is liable to
1347 Change, we have already demonſtrated; let us conceive ſeveral Moons to be at the ſame Diſtance, revolving in equal Times about the Earth, in a Plane inclined to the Plane of the Ecliptic; it is plain they will all be agitated by the ſame Motions: Let us conceive the Number of the Moons to be encreaſed, ſo as to touch one another, and form a Ring, whoſe Parts cohere; whilſt one Part of the Ring is attracted, to encreaſe the Inclination, the other Part is
1376 agitated by a contrary Motion, to diminiſh its
1345 Inclination; the greater Force in this Caſe pre-
1377 vails, that is, *in the Motion of the Line of Nodes, from the Quadratures towards the Syzygies, the Inclination of the Ring is diminiſhed in each of its*
*1349 *Revolutions;** *and it is the leaſt of all, when the*
*1350 *Line of Nodes is in the Syzygies.** On the contrary, *its Inclination is encreaſed, when the Line of Nodes is carried from the Syzygies towards the Quadra-*
*1351 *tures;** *and it is the greateſt of all, when the Line of*
1378 *the Nodes is in theſe laſt.** *The Line of the*
*1352 *Nodes is continually carried in* Antecedentia, *un-*
*1341 1344 *leſs when it is at reſt in the Syzygies.**

1379 *If the Quantity of Matter in the Ring be diminiſhed, its Motions will not be changed*; becauſe they depend upon Gravity, which acts equally up-
1027 on every Particle of Matter.

If

If the Diameter of the Ring be diminiſhed, theſe 1380
Motions are diminiſhed in a Ratio of this Diminution,* but none of them wholly vaniſh; and *1354
it is agitated by the ſame Motions.

Let us conceive the Earth to be ſpherical; and 1381
in the Plane of the Æquator, which makes an Angle of 23 Degr. 29 Min. with the Plane of the Ecliptic, let there be a Ring, revolving in the ſame Time as the Earth; let it be diminiſhed ſo as to touch the Earth, and cohere with it; by this the aforeſaid Motion of the Ring will not be deſtroyed; for ſince the Earth is kept in a determinate Situation by no Force, it yields to the Impreſſions of the Ring, whoſe Agitations are yet diminiſhed, the Matter to be moved being encreaſed, and the moving Power remaining the ſame.

And this is truly the Caſe, for the Figure of the Earth is ſpherical, encompaſſed with a Ring at the Æquator, whereby the Earth is more elevated towards the Æquator,* the Line of Nodes *1370
of which Ring is the Section of the Planes of the Æquator and Ecliptic. Whence we deduce the following Concluſions.

In the Æquinoxes, the Inclination of the Æ- 1382
quator is leaſt of all;* and therefore *the Incli-* *1377
nation of the Axis is the greateſt; for it makes a right Angle with the Plane of the Æquator.* *1075
The Inclination of the Æquator is encreaſed, that
is, *the Inclination of the Axis is diminiſhed, till* 1383
the Sun comes to the Solſtices, where this Inclination of the Axis is leaſt of all, and that of the Æquator the greateſt.* Therefore *twice in a Year the In-* *1377
clination of the Axis of the Earth is diminiſhed, and twice encreaſed. And *the Section of the Plane of the* 1384
Æquator with the Plane of the Ecliptic, which *is* 1385
at reſt in the Æquinoxes, the reſt of the Time is moved in Antecedentia.*
*1378

The

1386 The Plane of the Æquator is enclined to the Plane of the Moon's Orbit; for it makes a ſmall
969 Angle with the Plane of the Ecliptic: And therefore the Moon acts in the ſame Manner upon the Ring as the Sun; and although the Moon be leſs, yet, becauſe it is much leſs diſtant than the Sun, it exerts a greater Action upon the Ring.
1387 Wherefore alſo *the Inclination of the Axis of the*
*1384 *Earth to the Plane* of the Moon's Orbit* (and conſequently to the Plane *of the Ecliptic*) *is twice changed in every Revolution, and twice reſtored by the Action of the Moon: And the Section of the Plane of the Æquator*, with the Plane of the Moon's
1385 Orbit, *is carried in* Antecedentia: From which Motion neceſſarily follows, that the Section of the Plane of the Æquator, *with the Plane of the Ecliptic, changes its Place.*
1388 *The Changes of the Inclination of the Axis are too ſmall to be obſerved; but the change of Place of the*
1389 *Line of the Equinoxes, and the Motion of the Axis* which follows from it, being always carried the ſame Way, *at laſt become ſenſible*; and from theſe
1185 follow the Phænomena before explained.
1186

CHAP. XIX.

Concerning the Tides.

THAT we may explain the Tides from the Principles already laid down, we muſt conſider, that the Earth, as alſo all Bodies near it,
1206 gravitate towards the Moon; therefore the Particles of Water in the Earth's Surface which tend towards the Center of the Earth (for here we neglect the Conſideration of N° 1371.) are carried with it towards the Moon. Since alſo the ſolid Maſs of the Earth is carried towards the Moon, according to the Laws, which would obtain

obtain, if all the Matter of which it conſiſts was collected in its Center;* *what has been demonſtrated in* Chap. 16. *of the Action of the Sun upon the Moon* falling towards the Earth, whilſt with the Earth it goes towards the Sun, *may be applied to the Action of the Moon upon the Particles of Water in the Earth's Surface*, which do not cohere with the Maſs of the Earth, but tend towards its Center, and continually with its Maſs fall towards the Moon; by which Force, as we have ſhewn,* the Earth is kept in its Orbit, about the common Center of Gravity of the Earth and the Moon. *1126 1390 *1280

Plate XXV. *Fig.* 1.] Let S be the Moon; ALBL*l* the Surface of the Earth, whoſe Maſs tends towards the Moon, as if it was all collected at T; by the Action of the Moon, the Particles of Water, A and B, acquire a greater Gravity towards T;* on the contrary, the Particles at L, *l*, loſe of their Gravity;* whence we deduce, that if the whole Earth was covered with Water, there would not be an *Æquilibrium*, unleſs this Water was more elevated in the Points L and *l*, than in a whole Circle 90 Degrees diſtant from theſe Points; and therefore paſſing through the Points A and B. Therefore *by the Action of the Moon, the Water acquires a ſpheroidical Figure, formed by the Revolution of an Oval about its greater Axis, which, being continued, goes through the Moon.* 1391 *1287 *1296 1392

Let us ſuppoſe the Moon in the Æquator; all the Sections of the Earth which are parallel to the Æquator, as they are alſo parallel to the Axis of the Spheroid* are Oval, whoſe greater Axes paſs through the Meridian of the Moon; whence it follows, that *the Earth being at Reſt, in any Circle of Latitude, the Water is more elevated* 1393 *1392

in the Meridian in which the Moon is, and in th oppoſite Meridian, than in the intermediate Places.

Definition.

1394 The Lunar Day *is the Time ſpent between the Moon's going from the Meridian and coming to it again.* This Day is divided into 24 Lunar Hours: It is 50 Minutes longer than the Natural Day.

From the Motion of the Earth round its Axis, every Lunar Day, every Place paſſes through the Meridian of the Moon and the oppoſite Meridian, that is, twice paſſes through that Place,
1395 where the Water is raiſed *by the Action of the Moon*, and twice through that Place, where the
1393 Water is diſperſed by the ſame Action; and ſo *in a Lunar Day the Sea is twice elevated, and twice depreſſed, in any aſſigned Place.*

1396 By the Motion of the Earth round its Axis, the elevated Water continually recedes from the Meridian of the Moon; yet by the Action of the Moon, the Axis of the Spheroid paſſes
1392 through the Moon; therefore the Water is continually agitated, that the Elevation, which (on Account of the Motion of the Earth) is removed, may be brought under the Moon. Therefore the Water continually flows from A and B (*Plate* XXV. *Fig.* 1.) towards L and *l*, whilſt, by the Motion of the Earth, the Elevation is carried from L towards B, and from *l* towards A; that is, between L and B, as alſo between *l* and A, there are two contrary Motions, by which the Water is accumulated; ſo that the greateſt Elevations are between theſe Points (*viz.*) not directly under the Moon, but on one Side of that Point, and likewiſe aſide of
1397 the oppoſite Point. That is, in any Place, *the Water moſt elevated, two or three Hours after the Moon*

Moon has paſſed the Meridian of the Place, or the oppoſite Meridian.

The Elevation towards the Moon a little exceeds 1398
the oppoſite one. The Aſcent of the Water is dimi-* *1390
niſhed, as you go towards the Poles, becauſe there 1295
is no Agitation of the Water there.

What has been demonſtrated, in relation to 1399
the Moon, may be applied to the Sun; therefore 1400
from the Action of the Sun, every natural Day, the 1401
Sea is twice elevated, and twice depreſſed. This* *1395
Agitation is much leſs, on account of the immenſe
Diſtance of the Sun, *than that which depends upon the Moon*; yet *it is ſubject to the ſame Laws.* 1402

The Motions, which depend *upon the Actions of* 1403
the Moon and Sun, are not diſtinguiſhed, but confounded; and from the Action of the Sun, *the Lunar Tide is only changed*; *which Change varies every Day*, by reaſon of the Inequality between 1404
the Natural and Lunar Day*. *1394

In the Syzygies, the Elevation, from the Actions 1405
of both Luminaries, concur, and *the Sea is more elevated*; *the Sea aſcends leſs in the Quadratures*; for where the Water is elevated by the Action of the Moon, it is diſperſed by the Action of the Sun, and ſo on the contrary. Therefore, *whilſt* 1406
the Moon paſſes from the Syzygy to the Quadrature, the daily Elevations are continually diminiſhed: On the contrary, *they are encreaſed when the Moon moves the Quadrature to the Syzygy. At a New* 1407
Moon alſo, *cæteris paribus, the Elevations are greater, and thoſe that follow one another the ſame* *1398
*Day, are more different than at a Full-Moon.** 1402

The greateſt and leaſt Elevations are not obſerved, 1408
till the ſecond or third Day after the New or Full Moon; becauſe the Motion acquired is not preſently deſtroyed from the Attrition, and other Cauſes, by which acquired Motion the Aſcent of the Water is encreaſed. Although the Action by

which the Sea is raiſed be diminiſhed; ſomewhat like to what we have demonſtrated elſewhere con-
1174 cerning Heat.

1409 If now we conſider the Luminaries receding from the Plane of the Æquator, we ſhall perceive that *the Agitation* is diminiſhed, and *becomes leſs, according as the Declination of the Luminaries becomes greater.* Which plainly appears, if we conceive them to be in the Poles; for then the Axis of the ſpheroidical Figure coincides with the Action of the Earth; and all the Sections that are parallel to the Æquator, are perpendicular to the Axis of the Spheroid; and therefore circular. So that the Water, in every Circle of Latitude, will have every where the ſame Elevation; and ſo in the Motion of the Earth, the Height of the Sea is not changed in particular Places. If the Luminaries recede from the Poles, it is eaſy to find, that the Agitation will be more and more encreaſed, till it be the greateſt of all, the Spheroid revolving about a Line perpendicular to the Axis, the Axis of the Spheroid being ſuppoſed in the Plane of the Æquator.

1410 Hence it is plain, why *in the Syzygies, near the Æquinoxes, the Tides are obſerved to be the greateſt*, both Luminaries being in or near the Æquator.

1411 *The Actions of the Moon and Sun are greater, the*
*1354 *leſs thoſe Bodies are diſtant from the Earth**; but
*1390 when the Diſtance of the Sun is leſs, and it is in the South Signs, often both the greateſt Æquinoctial Tides are obſerved in that Situation of the Sun; that is, before the Vernal, and after the Autumnal Æquinox, which yet does not happen every Year; becauſe ſome Variation may ariſe from the Situation of the Moon's Orbit, and the Diſtance of the Syzygy from the Æquinox.

Plate

Plate XXV. *Fig.* 8.] *In Places diſtant from the* 1412
Æquator, as the Luminaries recede from the Æquator, the Elevations, that happen the ſame Day, are unequal. Let P P be the Axis of the Earth, E E the Æquator, L *l* a Circle of Latitude; A B the Axis of the ſpheroidical Figure which the Water forms: When a Place in the Circle L *l* is given at L or *l*, it is given in the ſame Meridian with the Axis of the Spheroid, and the Water is moſt elevated, in both Caſes; yet at L it is more elevated than at *l*; for C l exceeds C *l*, which Lines meaſure the Heights of the Waters, that is, the Diſtances from the Center: Theſe Lines would be equal if A L and B *l* (which are the Diſtances from the Axis of the Spheroid) were equal. But C *l* is leſs, becauſe B *l* exceeds A L, which ariſes from the Inclination of the Axis of the Spheroid to the Æquator.

As long as the Moon is on the ſame Side of the 1413
Æquator in any Place, that is, towards the Line C A continued, *the Elevation of the Water is ob-* 1414
ſerved to be greateſt every Day, after the Moon has paſſed the Meridian of the Place; for there is the greateſt Elevation when the Place is come to L; but *if the Æquator* ſeparates, or *is between* the *Moon and the Place*, of which we ſpeak, that is, if the Moon be towards the Line C B continued, the Water again at L will come to the greateſt Height, and, *every Day, the greateſt Elevation of the Sea will be, after the Moon has paſſed through the oppoſite Meridian.*

All Things, which have been hitherto explained, would exactly obtain, if the whole Surface of the Earth was covered with Sea; but ſince the Sea is not every where, ſome Changes ariſe from thence, not indeed in the open Sea; becauſe the Ocean is extended enough to be ſubject to the Motions we have ſpoken of. But

1415 *the Situation of the Shores, the Streights, and many other Things depending upon the particular Situation of the Places, diſturb theſe general Rules.* Yet it is plain from the moſt general Obſervations, that the Tide follows the Laws which we have explained. What remains is, to determine the Forces with which the Sun and Moon act upon the Sea, that it may appear, that they are able to produce the Effects which we have mentioned; and that the Actions of thoſe Bodies, upon Pendulums and other Bodies, are inſenſible.

1416 The Encreaſe or Addition to the Gravity of the Moon in the Quadratures, from the Action of the Sun, is to the Gravity of the Moon to-
1291 wards the Earth, as 1 to 178, 73. In which Computation we have ſuppoſed the mean Diſtance of the Moon from the Center of the
1285 Earth to be 60 Semidiameters of the Earth: Therefore the Gravity of the Moon is to the Gravity of the Earth's Surface, as 1 to 60 × 60
1208 =3600. Therefore the above-mentioned Encreaſe is to the Gravity on the Earth's Surface, as 1 to 643428, in which Computation there is an Error to be corrected.

This Computation would be exact, if the Encreaſe, of which we ſpeak, was to the Force, with which the Earth deſcends towards the Sun, as the Diſtance of the Moon (which is 60 Semidiameters of the Earth) to the Diſtance of
1287 the Earth from the Sun; but it is as the true mean Diſtance of the Moon, which is 60½ Semidiameters of the Earth to the Diſtance of the Earth from the Sun. Wherefore the Encreaſe, that we have juſt determined, ought to be $\frac{1}{120}$ Part encreaſed, and will be to the Force of Gravity on the Earth's Surface, as 1 $\frac{1}{120}$ to 643428, or as 1 to 638110, 4.

This Encreaſe of the Gravity of the Moon, in the Quadratures from the Action of the Sun,

is to the Encreaſe of the Gravity of the Water on the Earth's Surface, in Places which are 90 Degr. diſtant from the Sun (from the ſame Action of the Sun) as 60½ to 1*. Therefore this Encreaſe of the Gravity is to the Gravity of the Water, as 1 to 38605679. The Diminution of the Gravity, under the Sun, and in the oppoſite Place, is double this Encreaſe *; therefore it is to the Gravity as 1 to 1930 839, and *the* whole *Change in the Gravity, ariſing from the Action of the Sun, is to the Gravity itſelf, as* 1 *to* 12868560. *1288 *1296 1417

In order to compare the Action of the Moon with the Action of the Sun, we muſt make Experiments in Places, in which, by reaſon of the Narrowneſs, the Sea is ſenſibly raiſed. Near *Briſtol* at the Autumn and Spring, at which Times the Agitation of the Sea is greateſt*, the Water aſcends in the Syzygies about 45 Feet, more or leſs, in the Quadratures about 25 Feet, more or leſs. Which Numbers are to one another as 9 to 4. 1418 *1410

The Determination of the Forces, which we would find, if the greateſt and leaſt Elevations were exactly at the Time of the Syzygies, would be very eaſy, which we have ſhewn before not to happen ſo*. *1408

The Diſtance of the Moon from the Syzygy, or the Quadrature, is not always the ſame in the greateſt or leaſt Elevation; for this Diſtance varies, becauſe the Moon is ſometimes more, and ſometimes leſs diſtant from the Meridian, when it goes through the Syzygy or Quadrature. The mean Diſtance of the Moon from the Syzygy, or Quadrature, to which the aforeſaid Obſervations ought to be referred, is about 18 Degr. 30 Min. ſo that the whole Action of the Sun neither conſpires with the Action of the Moon in the Syzygies, nor acts contrary to it in the Quadratures. Alſo in ſuch a Caſe, if at

the Syzygy, both the Luminaries be in the Æquator, in the ſaid Diſtance from the Quadrature, the Declination of the Moon is 22 Degr. 13 Min. more or leſs; whereby the Force of the Moon to
1409 move the Sea is diminiſhed. Beſides, *cæteris paribus*, the Diſtance of the Moon from the Earth
1310 at the Syzygies is leſs than at the Quadratures;
1311 whence alſo the Action of the Moon is diminiſh-
1411 ed at the Quadratures: By attending to all which Things we may diſcover, that *the mean Force of*
1419 *the Sun, to move the Sea, is to the mean Force of the Moon to move the ſame, as* 1 *to* 4,4815. But the Force of the Sun is to the Force of Gravity, as
1417 1 to 12868560; wherefore *the Force of the Moon is to the* ſame *Force of Gravity as* 1 *to* 2871485.
1420 From whence it follows, that theſe Forces of the Moon and Sun are too ſmall to be ſenſible in Pendulums and other Experiments; but it is eaſily proved, that they are capable of agitating the Sea.

By diminiſhing the Gravity $\frac{1}{289}$ Part, the Sea
*1368 is raiſed to the Height of 88902 *Rhynland* Feet*.
1417 For each Perch contains 12 Feet; whence, by the
1421 Rule of Proportion*, we find that *the Action of*
1422 *the Sun changes the Height of the Sea two Feet,*
*1419 *and that the Action of the Moon changes it* 8, 95;* *and that from the joined Action of both, the mean Agitation is of about eleven Feet*, which agrees pret-
1423 ty well with Obſervations; for in the open Ocean, as the Sea is more or leſs open, the Water is raiſed to the Height of Six, Nine, Twelve, or Fifteen Feet; in which Elevations alſo there is a Difference ariſing from the Depth of the Waters. But thoſe Elevations, which far exceed theſe, happen, *where the Sea violently enters into*
1424 *Streights or Gulphs*; where *the Force is not broken, till the Water riſes higher.*

CHAP.

CHAP. XX.

Of the Moon's Denſity and Figure.

THE Forces of the Sun and Moon, for giving Motion to the Sea, are to one another, in a Ratio compounded of the Ratio of the Quantities of Matter in theſe Bodies* (for all the Particles of Matter act) and the inverſe Ratio of the Cubes of the Diſtances of the Sun and Moon from the Earth.* 1425 *1207 *1390

The Quantities of Matter are in a Ratio compounded of the Ratio of the Bulks, that is, of the Cubes of the Diameters, and the Ratio of the Denſities;* wherefore the Forces above-mentioned are directly as the Denſities and the Cubes of the Diameters, and inverſly as the Cubes of the Diſtances. 1402 1354 *288 79

The apparent Diameters of Bodies, that is, the Angles under which they are ſeen, encreaſe as the Diameters themſelves, and diminiſh as the Diſtances; that is, they are directly as the Diameters, and inverſly as the Diſtances; therefore the Ratio compounded of the Ratio's of the Cubes of the apparent Diameters *of the Sun and Moon*, and of the Ratio of the Denſities, will be the Ratio of the Forces, whereby thoſe Bodies act upon the Sea. Therefore the *Denſities* of thoſe Bodies *are directly as the Forces, whereby they move the Sea, and inverſly as the Cubes of their apparent Diameters*; and dividing the Forces by the Cubes of thoſe Diameters, you have the Ratio of the Denſities. 1426

The

The Force of the Sun is to the Force of the
1419 Moon, as 1 to 4, 4815; the mean apparent Diameter of the Sun is 32 Min. 12 Sec. and the mean apparent Diameter of the Moon is 31 Min. $16\frac{1}{2}$ Sec. That is, they are to one another, as 14273864 to 3753. Therefore *the Denſity of the Sun is to the Moon's Denſity, as* 10000 *to* 48911: which Denſity of the Moon may be compared with the
*1260 Denſities of *Jupiter*, *Saturn*, and the Earth*, and the Moon is denſer than the Earth.

The Quantities of Matter in two Bodies are to one another, in a Ratio compounded of the
79 Denſities and Bulks; that is, if the Body be a Sphere, in a Ratio compounded of the Denſities and the Cubes of the Diameters.

1428 *The Denſites of the Moon and Earth are to one*
*1427 *another*, as 48911 to 39214*; the Diameters
1260 as 11 to 40, 2. therefore the *Quantities of Matter*, in thoſe Bodies, *are as* 1 *to* 39, 13. Though the Denſities be diſcovered, if you ſuppoſe the Bodies to be homogeneous; yet the Quantities of Matter will be rightly defined, though the Bodies are not homogeneous; for we determine the Denſity which that Body would have, if the Matter, of which the Body really conſiſts, was equally diffuſed all over it.

1429 *The Gravities, on the Surfaces of the Earth and Moon, are* determined, by multiplying the Denſi-
1230 ties by the Diameters, that is, they are to one another, as 2, 93 to 1, or *as* 407,8 *to* 139, 2. Which Number alſo does expreſs the Relation of Gravity on the Surface of the Moon, with the Gravity on the Surfaces of the Sun, *Jupiter* and
*1258 *Saturn.**

1430 *The common Center of Gravity of the Moon and Earth*, about which both Bodies are moved, is determined; for its Diſtance from the Center of the

the Earth, *is to the Diſtance* between the Centers of both Bodies, as the Quantity of Matter in the Moon to the Quantity of Matter in both Bodies;* therefore 40, 13. is to 1: as the Diſtance of the Moon from the Earth, is to the required Diſtance of the Center of Gravity, *from the Center of the Earth*, which is found to be *of* 5126950 *Perches*, as is deduced from the known Diameter of the Earth*, and the Diſtance of the Moon. *234 235 *976

To determine the Figure of the Moon, we muſt examine what Figure it would have, if it was fluid*. If we conſider the Moon alone at reſt, it would be ſpherical:* If we conſider the Action of the Earth upon the Moon, the Moon would acquire the Figure of a Spheroid, whoſe Axis would go through the Earth*. The Force of the Earth, for changing the Figure of the Moon, is to the Force of the Moon upon the Earth, as 39, 13. to 1.* and as the Diameter of the Moon to the Earth's Diameter,* which are to one another as 11 to 40, 2. and it is a Ratio compounded of theſe 10 7. to 1. This Force of the Moon is to the Gravity upon the Earth's Surface, as 1 to 2871485;* which Gravity, on the Earth's Surface, is to the Gravity on the Surface of the Moon, as 407, 8, to 139, 2.* or as 2871485, to 980028: Wherefore *the Action of the Earth, for changing the Moon's Figure, is to the Gravity upon the Moon's Surface, as* 10, 7. to 980028, *or as* 1 *to* 91524, the Gravity being changed on the Earth's Surface, by $\frac{1}{2871485}$ Part the Water is raiſed 8, 95 Feet;* and therefore if Gravity was to be changed $\frac{1}{915}$ Part, the Elevationed would be of 280, 7 Feet, as it is found by the Rule of Three. If, keeping this Diminution of Gravity, we conſider a leſs Body, this Height muſt 1431 *1358 *1359 *1392 *1418 1207 *1390 1354 *1420 *1429 1432 *1420 1422

muſt be diminiſhed, in Proportion to the Diameter: Therefore, from the Action of the Earth, the Elevation of the Moon is of 76, 8 Feet; and if the
1433 Moon be homogeneous, *there will not be an Æquilibrium, unleſs the Axis of the Spheroid exceeds the Diameter, which is perpendicular to it*, 153, 60 Feet.

1434 *The Elevation of the Moon*, from the Action *of the Earth*, may be diſcovered by one ſingle Proportion, by knowing the Elevation of the Sea from the Moon's Action; for theſe Elevations *are in a duplicate inverſe Ratio of the Gravities on the Surfaces of thoſe Bodies.*

1435 If, ſuppoſing this to be the Figure of the Moon, we conceive the Parts to cohere, *there will not be an Æquilibrium between the Parts of the Moon, unleſs* the Axis of the Spheroid be directed towards the Earth; whence we ſee the Reaſon, why *the Moon always turns the ſame Face towards the Earth*; by which continual Agitation, the Moon
1436 has at leaſt acquired *the Motion about its Axis* of
970 which we have before ſpoken; which Motion
1092 *muſt neceſſarily be performed in the ſame Time, as the Moon performs one Revolution*; for from the Action above-mentioned, it muſt neceſſarily adapt itſelf to ſuch a Celerity; for if the Celerity was greater, it would be continually retarded by the Force, whereby the ſame Face is always directed towards the Earth; and, if this Celerity was leſs, it would be continually accelerated. Yet this Force is not great enough, ſenſibly to diſturb the Æquibility of the Motion acquired a-
1437 bout the Axis, every Revolution: Therefore *the Motion about the Axis is equable, though the Moon*
*966 *be moved in its Orbit by an unequal Motion**. The Poſition alſo of the Moon's Axis cannot be ſo changed by the Force above-mentioned, as to become

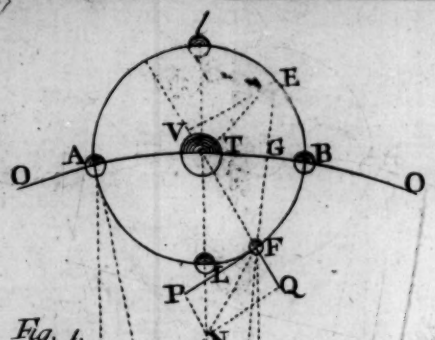


Fig. 1.

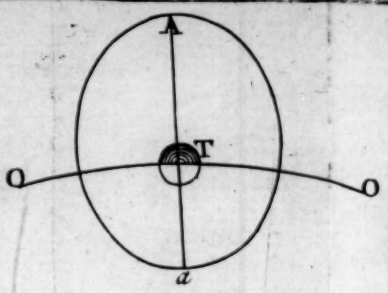


Fig. 2.

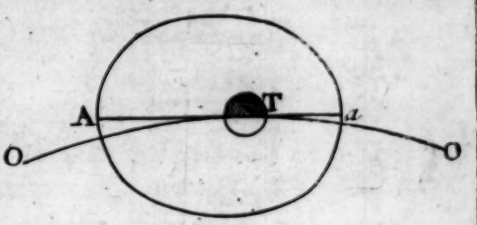
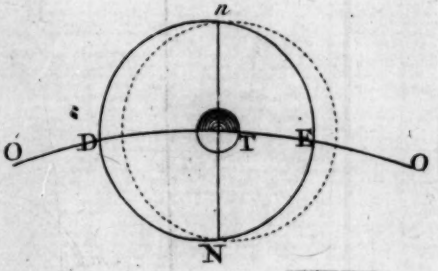


Fig. 3.









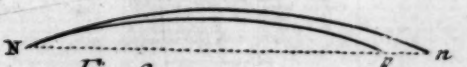


Fig. 6.



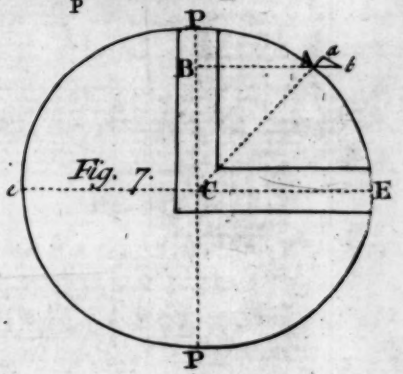


Fig. 7.

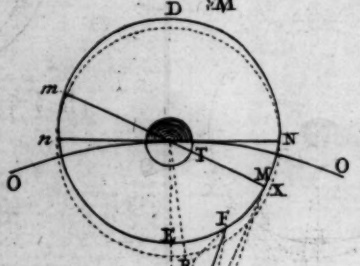


Fig. 4.

Fig 5





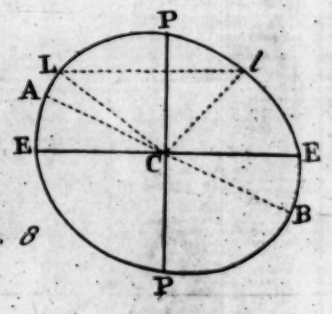
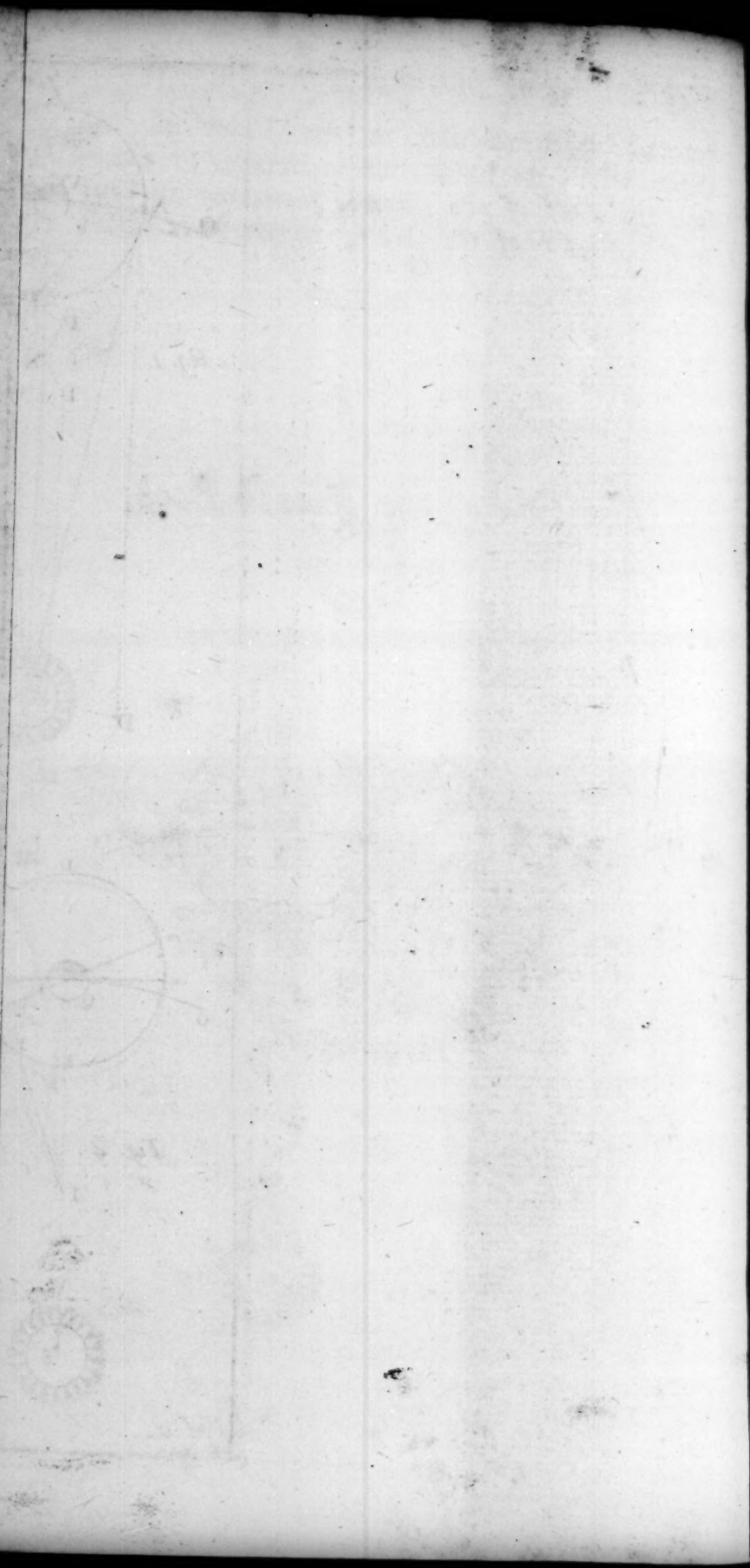


Fig. 8

Vol. 2.



become perpendicular to the Plane of the Orbit, when its Inclination is changed;* therefore *the Axis of the Moon is ſometimes inclined to the Plane of the Orbit*, as we have before ſhewn*. *1345 1438 *1093

The End of the Fourth Book.

A N

INDEX.

The Numbers (1.) *and* (2.) *refer to the first and second Volume.* p. *stands for Page, and* n. *for the Number in the Margin.*

A.

ACceleration *of heavy Bodies* (1.) p. 52. n. 129. and the following Acceleration *of Bodies rolling down upon an inclined Plane*, p. 58. n. 144. and fol. 135. and fol.

Æolipile (2.) *p.* 21. *n.* 606, 607.

Æquation *of Time.* (2.) p. 194, 1145.

Æquator (2.) *p.* 181. *n.* 1075. *p.* 188. *n.* 1114.

Æquinox (2.) *p.* 15. *n.* 1155.

——*Preceſſion of the* Æquinoxes, *p.* 201. *n.* 1186. *p.* 203. *n.* 1193.

——*the Explanation of this Motion*, p. 27. n. 1382. and f.

Air *ranked amongſt the Fluids* (1.) p. 209. n. 417. and fol.

—— *weighed*, p. 223. n. 442.

——*endowed with Elaſticity*, p. 212. n. 426. and fol.

——*conſiſting of ſeparated Particles.* p. 216. n. 431.

——*Experiments relating to it*, p. 223. n. 442. and fol.

——*The Vehicle of Sound*, p. 249. n. 504.

——*Its Action upon Fire.* See *Fire.*

Air-Pump, (1.) *p.* 219. *n.* 435. and fol.

Al-

Altitude or *Height of the Stars* (2.) p. 187. n. 1105.
——— *of the Pole*, p. 190. n. 1126.
Amplitude *of the Stars*, p. 187. n. 1104.
Angle *of Incidence* (2.) p. 28. n. 621.
——— *of Refraction*, ibid. n. 623.
——— *of Reflection*, p. 81. n. 781.
Animals cannot live without Air (1.) p. 232. n. 463.
——— *in condenſed Air*, p. 233. n. 465.
Aphelia *of Planets* (2.) p. 152. n. 935.
Apſides *of Planets* (2.) p. 152. n. 937.
The Line of Apſides, p. 152. n. 938.
Aſcent of *Fluids in capillary Tubes* (1.) p. 13. n. 35.
——— *even in a Vacuum*, ibid. n. 36.
——— *between two Glaſs Planes*, p. 14. n. 37, 38.
Aſteriſms, *p.* 202. *n.* 1190. and fol.
Atmoſphere (1.) *p.* 209. *n.* 418.
Attraction (1.) *p.* 11. *n.* 31.
——— ——— *the Laws of it*, ibid.
——————*from Gravity* (2.) p. 207. n. 1210.
The Space of Attraction (2.) p. 31. n. 632.
Auges. See *Apſides.*
Axioms *concerning Motion* (1.) p. 21. n. 58. and fol.
Axes *of a Planet* (2.) p. 154. n. 949.
The Motion of the Axis *of the Earth*: See *the Preceſſion of the Æquinoxes.*
Axis in Peritrochio (1.) p. 38. n. 112.
———*the Properties of it*, p. 39. n. 113. and fol.
Axis *of a Balance*, p. 28. n 24.

B.

Balance, *its Properties* (1.) p. 28. n. 17. and fol.
——— *the Perfection of one*, p. 24. n. 102.
——— *Falſe* Balance, *p.* 30. *n.* 92.
———*Hydroſtatical* Balance, *p.* 134. *n.* 127.
——— *Roman* Balance (1.) *p.* 30. *n.* 91.
Blackneſs: See *Reflection.*
Black *Bodies grow warm ſooner than Bodies of other Colours* (2. p. 145. n. 909.
Body, *its Properties* (1.) p. 4. n. 8. and fol.

Burning *Glaſſes* (2.) p. 56. n. 703.

C.

Celerity (1.) *p.* 20. *n.* 53.
——— *relative*, p. 75. n. 175.
Center *of a Balance* (1.) p. 28. n. 85.
Center *of Gravity* (1.) p. n. 95.
——— *Its Properties*, ibid. n. 96. and fol.
——— *of Oſcillation*, p. 65. n. 161.
——— *of Percuſſion*, p. 65. n. 162.
Central *Forces* (1.) p. 105. n. 220.
——— *their Properties*, p. 105. n. 221. and fol.
——— *compared together*, p. 112. n. 231. and fol.
Centrifugal *Force* (1.) p. 104. n. 218.
Centripetal *Force* (1.) 1. p. 105. n. 219.
Dark Chamber (2.) p. 59. n. 711. p. 92. n. 817.
The Law of Coheſion (1.) p. 11. n. 31.
Colour *of Objects* (2.) p. 116. n. 859.
——— *of Rays*, ibid. n. 860.
This laſt Colour *is always unchangeable*, p. 117. n. 863: and fol. p. 123. n. 869.
The Order of Colours, *according to their different Refrangibility*, p. 117. n. 861.
——— *mixed* Colours, *p.* 127. *n.* 873, 874.
From whence Colours *come to be dull or lively*, p. 146. n. 911, 915.
Why Colours *vary in ſome Bodies according to the Situation of the Eye*, ibid. 914.
The Change of Colours *in Liquids mixed*, p. 146. n. 916.
A Liquid appearing of a different Colour, *according as it is ſeen by reflected or tranſmitted Rays*, p. 147. n. 917.
The Colours *of the Clouds*, ibid. 148. n. 920.
——— *of thin Plates*, p. 136. n. 887.
——— *their Properties*, ibid. and fol.
——— *of Bodies, from whence they proceed*, p. 144. n. 907. p. 146. n. 910.
Comets (2.) p. 159. n. 979. and fol.
——— *their Motions explained* (2) p. 240. n. 1276. and fol.

The

The Conjunction *of the heavenly Bodies* (2.) p. 167. n. 1010.
Conſonances (1.) *p.* 255. n. 525. and fol.
Courſe *of a River* (1.) p. 195. n. 392. and fol.
How to meaſure the Swiftneſs of its Courſe, p. 199. n. 399. and fol.
Rock Chryſtal *made lucid by rubbing* (2.) p. 3. n. 552.

D.

Natural Day (2.) *p.* 193. n. 1141.
Artificial Day, *p.* 194. *n.* 1147.
Their Differences, ibid. *n.* 1152. and fol.
Lunar Day, *p.* 274. *n* 1394.
Declination *of a Star* (2.) p. 182. n. 1079.
Degrees *of Latitude encreaſe, as you come nearer the Poles* (2.) p. 269. n. 1374.
Denſity (1.) *p.* 146. *n.* 284.
How to determine the Denſity *of Fluids* (1.) p. 155. n. 309. and fol.
The Denſities *of Planets* (2.) p. 231. n. 1260.
Dilatation by Heat. See *Heat.*
Ditonus (1.) *p.* 255. *n.* 530.
Diviſibility *of Matter* (1.) p. 4. n. 10. p. 5. n. 17. and fol *p.* 10. *n.* 26.
Drop *becomes ſpherical* (1.) p. 12. n. 33.

E.

The Earth *ranked amongſt the Planets* (2.) p. 155. n. 960.
—— *its Motion and Diſtance*, ibid. *n.* 960 *p.* 164 *n.* 996. and fol. *p.* 182. *n.* 1081. and fol. *p.* 200. *n.* 1183. and fol. *p.* 222. *n.* 1244. and fol. *p.* 242. *n.* 1281.
——— *its Dimenſions*, p. 158. n. 976.
—— *its Figure*, p. 264. n. 1360. and fol.
——— —— *it cannot be determined by Meaſures*, p. 269. n. 1375.
——— *its Elevation towards the Æquator determined*, p. 268. n. 1370.
—— *the Degrees on its Surface encreaſe as they draw nearer the Poles*, p. 269. n. 1374.

Point of the East (2.) *p.* 187. *n.* 1102.
Echo (1.) *p.* 258. *n.* 542.
Eclipse *of a Satellite* (2.) p. 175. n. 1033.
——*of the Moon.* See *Moon.*
——*of the Sun.* See *Sun.*
Ecliptic *Line* (2.) p. 165. n. 999.
Plane of the Ecliptic, *p.* 153. *n.* 940.
Elasticity (1.) *p.* 17. *n.* 44.
Perfect Elasticity, *p.* 76. *n.* 177.
The Law of Elasticity (1.) *p.* 123. *n.* 251.
The Elasticity *of Fibres*, p. 120. n. 244. and fol.
The Elasticity *of Plates of Metal*, p. 129. n. 262. and fol.
The Elasticity *of a Ball*, p. 131. n. 266.
Elasticity *from Heat.* See *Heat.*
Electricity (2.) *p.* 3. *n.* 551.
——*of a Glass Tube*, ibid. n. 554, 555.
——*of a Glass Globe*, p. 5. n. 559. and fol.
Conjectures about the Cause of it, p. 7. n. 563. and fol.
The Elongation *of Planets* (2.) p. 167. n. 1012.
The greatest Elongation, *ibid. n.* 1013.
Excentricity *of Planets* (2.) p. 152. n. 932.
Extension (1.) *p.* 4. *n.* 8. *p.* 5. *n.* 13.
Description of the Eye (2.) *p.* 60. *n.* 712.
Artificial Eye (2.) *p.* 62.
Changes in the Eye, *p.* 63. *n.* 719. and fol.
The Defect of old Eyes *corrected*, p. 72. n. 756.
The Defect of short-sighted Eyes *corrected*, p. 73. n. 758.

F.

Fibres—their Elasticity (1.) p. 120. n. 244. and fol.
——their Vibrations, *p.* 127. *n.* 257. and fol.
Properties of Fire (2.) *p.* 1. *n.* 544. and fol.
Fire *contained in Bodies* (2.) p. 3. n. 552. and fol.
The Action of Air upon Fire (2.) *p.* 12. *n.* 577. *p.* 17. *n.* 593. *p.* 18. *n.* 594.
A Fifth (1.) *p.* 255. *n.* 528.
Flame (2.) *p.* 15. *n.* 587. *p.* 17. *n.* 592.
Fluid (1.) *p.* 11. *n.* 30.
Wherein Fluids *agree with* Solids (1.) p. 134. n. 270.

The Properties of Fluids, *p.* 135. *n.* 272. and fol.
The Actions of Fluids *upon the Bottoms and Sides of Veſſels*, p. 138. n. 280.
The Motion of Fluids (1.) *p.* 174. *n.* 354.
Fluids *ſpouting vertically*, p. 177. n. 358. and fol.
See *Fountain.*
——*Spouting obliquely*, p. 178. n. 360 and fol.
——*Spouting out of Veſſels*, p. 188 n 378. and fol.
Compariſon of the Times in which Veſſels become empty, p. 189. n 379. and fol.
Solids immerſed in Fluids, *p.* 147. *n.* 290 and fol.
——*heavier*, p. 148. n. 292. p. 149. n. 296. and fol.
——*lighter*, p. 154. n. 306. and fol.
Fluidity, *from whence it ariſes* (1.) p. 133 n. 269.
——*whether it depends upon Heat?* (2.) p. 20. n. 603.
Full Moon (2.) *p.* 175. *n* 1043.
Focus (2.) *p* 40. *n.* 650.
Fountain *of Hero* (1.) p. 237. n. 474.
——*from the Compreſſion of the Air*, p. 231. n. 459.
Two little Fountains, *p.* 230. n. 457. *p.* 230. *n.* 458.
A Fourth (1.) *p.* 255. *n.* 529.

G.

Glaſs *appears lucid by Attrition* (2.) p. 3. n. 553. p. 5. n. 557.
Burning Glaſſes (2.) *p.* 56. *n.* 703.
Gravity (1.) *p.* 25. *n.* 73. (2.) *p.* 296. *n.* 1206. and fol.
The Phænomena of Gravity (1.) *p.* 25. *n.* 72. *p.* 25. *n.* 75, 77.
Reſpective Gravity (1.) *p.* 149. *n.* 295.
Specific Gravity (1.) *p.* 146. *n.* 287.
Gravity *univerſal* (2.) p. 206. n. 1206.
The Laws of Gravity, *ibid.* n. 1207, 1208.
Gravity *is proved*, p. 207. n. 1211. and fol.
Propoſitions relating to Gravity, *p.* 213 *n* 1226. and fol.
Gravity *not to be aſcribed to any Impreſſion known to us*, p. 316. n. 1238.
Gravity *upon the Surfaces of Planets*, p. 231. n. 1258.

Hard Bodies (1.) *p.* 11. *n.* 28.
Heat (2.) *p.* 14. *n.* 579, 580, 584.
Heat *is not in Proportion to the Fire*, p. 15. n. 588.
Heat *makes Bodies emit Light or ſhine*, p. 16. n. 591.
—— *dilates Bodies*, p. 18. n. 596, 597.
——*melts ſome Bodies*, p. 20. n. 602.
——*gives Elaſticity to ſome Bodies*, ibid. *n.* 605.
——*What Sorts of Bodies grow ſooneſt warm*, p. 145. n. 908.
Heavens—*what they are* (2.) p. 161. n. 986.
——*why blue*, p. 162. n. 987.
Heavy *Bodies do not tend towards the Center of the Earth*, (2.) p. 368. n. 1371.
Heterogeneous *Body* (1.) p. 146. n. 286.
Heterogeneous *Rays* (2.) p. 109. n. 850.
Homogeneous *Body* (1.) p. 146. n. 285.
Homogeneous *Rays* (2.) p. 108. n. 849.
Horizon (2.) p. 185. n. 1096.

I.

Glaſs Images *going up and down in Water* (1.) p. 231. n. 462.
Inclined *Plane* (1.) p. 56. n. 139.
The Inertia *of a Body* (1.) p. 5. n. 12.
Iris *or Rainbow, when produced* (2.) p. 134 n. 884, 885.
Two frequently appear at a Time, p. 136. n. 886.
Explanation of the Motion of Light in forming a Rainbow, p. 127. n. 875. and fol.
Judgment *concerning the Diſtance and Magnitude of Objects.* See *Light.*
—— *concerning the Magnitude of the Sun and Moon, near the Horizon* (2.) p. 67. n. 735.
Jupiter (2.) *p.* 156. *n.* 962.
——*its Weight*, p. 231. n. 1255.
——*Gravity on its Surface*, p. *ibid.* n. 1258.
——*its Denſity*, p. *ibid.* n. 1260.
——*its Force acting on Saturn*, p. 236. n. 1270.
——*on Mars*, p. 238. n. 1273.
——*its Figure*, p. 9, 235. n. 1363.

De-

L.

Deſcription and Uſe of the magic Lantern (2.) *p.* 99. *n.* 837. and fol.
Perfection of a magic Lantern (2.) *p.* 102. *n.* 839.
Latitude *of an heavenly Body* (2.) p. 166. n. 1006.
——*of a Place*, p. 189. n. 1118.
Circle of Latitude, *p.* ibid. *n.* 1119.
Law *of Nature* (1.) p. 2. n. 4.
How the Laws *of Nature are diſcovered*, ibid.
Glaſs Lens (2.) *p.* 53. *n.* 692.
The Properties of Lenſes (2.) *p.* 54. *n.* 966.
Convex Lenſes, *p.* 55. *n.* 698. and fol.
Concave Lenſes, *p.* 57. *n.* 704. and fol.
Multiplying Lenſes, *p.* 73. *n.* 759.
Lever (1.) *p.* 35. *n.* 103, 104.
——*its Properties*, p. 35. n. 105. and fol.
Light (2.) *p.* 14. *n.* 581. and fol.
Bodies receive Light *from Heat.* See *Heat.*
A Ray of Light. See *Ray.*
The Motion of Light (2.) *p.* 16. *n.* 589, 590.
The Celerity of Light *in different Mediums*, p. 37. n. 640.
Inflection of Light, *p.* 24. *n.* 611. and fol.
—— *its Refraction.* See *Refraction.*
——*its Reflection.* See *Reflection.*
Bodies liquefied. See *Heat.*
Longitude *of an heavenly Body* (2.) p. 166. n. 1003, 1004.
Longitude *of a Place*, p. 189. n. 1121.

M.

Simple Machines (1.) *p.* 35. *n.* 103. *p.* 38. *n.* 112. *p.* 40. *n.* 115. *p.* 44. *n.* 119. *p.* 45. *n.* 121.
Compound Machines, *p.* 47. *n.* 122. and fol.
A Machine *by which the Properties of the Wedge are demonſtrated* (1.) p. 44. n. 120.
A Machine *to determine the Acceleration of falling Bodies*, p. 53. n. 132.
A Machine *to demonſtrate the Properties of an inclined Plane* (1.) p. 57. n. 143.

A Machine *for making Experiments concerning Percuſſion*, p. 68. n. 170.
——*for making Experiments concerning compound Motion, and oblique Percuſſion*, p. 86. n 191.
——*for oblique Powers*, p. 92. n. 197. p. 95. n. 203, 204.
——*for the Projection of heavy Bodies* (1.) p. 100. n. 210.
——*to ſhew the Central Forces*, p. 105. n. 222.
——*for making Experiments concerning Elaſticity*, p 122. n. 249.
——*to ſhew the Preſſure of Fluids*, p. 139. n. 281. p. 142. n. 282. p. 144. n. 283.
——*to find out the Denſity of Fluids*, p. 156. n. 312. p. 158. n. 314.
——*to compare the Denſities of Solids*, p. 159. n. 317, *and* 318.
——*to make Experiments concerning the Reſiſtance of Fluids*, p. 170. n. 346.
——*to make Experiments concerning Fluids ſpouting out*, p. 175. n. 356. p. 182. n. 370.
——*to meaſure the Celerity of a River*, p. 198. n. 398.
——*to let Bodies down into the Air Pump, when the Receiver is void of Air*, p. 26. n. 77.
——*to whirl Bodies round in a Vacuum* (2.) p. 8. n. 567.
——*to make Experiments in condenſed Air* (1.) p. 228. n. 454.
——*uſed by Divers*, p. 231. n. 461.
Various Machines, *the Effect of which depends upon the Action of the Air* (1.) p. 223. n. 467. and fol.
——*to whirl round a Glaſs Globe* (2.) p. 4. n. 556.
——*to ſhew the Inflection of Light*, p. 24. n. 611.
——*to ſhew the Refraction of Light*, p. 29. n. 630. p. 38. *in the Beginning*, p. 49. p. 55. n. 702. p. 58. n. 708.
Apparent Magnitude. See *Judgment and Sight.*

Mars (2.) *p.* 155. *n.* 961.
The cœleſtial Matter *very ſubtile* (2.) p. 221. n. 1243.
——— *it does not move Bodies*, p. 222. n. 1244.
The Quantities of Matter *in Planets* (2.) p. 231. n. 1255.
The Medium *of Light* (1.) p. 7. n. 15.
Mercury *ſhines in a Vacuum* (2.) p. 11. n. 571. and fol.
The Planet Mercury (2.) *p.* 155. *n.* 958.
Meridians (2.) *p.* 181. *n.* 1077. *p.* 188. *n.* 1114, 1116.
Firſt Meridian, *p.* 189. *n.* 1120.
Meridian *Line* (2.) p. 186. n. 1101.
Microſcope (2.) *p.* 74. *n.* 760.
——— *it magnifies ſmall Objects*, p. *ibid. n.* 761.
——— *it magnifies more when compounded*, p. 76. n. 765.
Milky *Way*, p. 284. n. 1199.
——*it is an Aſſemblage of Stars*, p. *ibid.* n. 1200.
Mirrours *or Looking Glaſſes plane* (2.) p. 87. n. 799. and fol.
——*ſpherical and convex*, p. 89. n. 806. and fol.
——*ſpherical and concave*, p. 90. n. 813. and fol.
——*burning*, p. 91. n. 814.
——*cylindric and conic*, p. 117. n. 863.
The Phænomena of the Moon (2.) p. 174. *n.* 1035. and fol.
Why it appears bigger near the Horizon, p. 67. n. 735.
It turns round its Axis, p. 157. n. 970. 184. n. 1092.
It always turns the ſame Face towards the Earth, p. 184. n. 1092.
Eclipſe of the Moon (2.) *p.* 176. *n.* 1047.
——*when it happens*, ibid. *n.* 1049. 1051.
——*Partial* p. 177. n. 1052.
——*Total*, ibid. *n.* 1053.
——*Central*, ibid. *n.* 1054.
The Gravity of the Moon *towards the Earth*, p. 211. n. 1225.

The Denſity of the Moon, *p.* 282. *n.* 1427.
The Gravity of the Moon *in its Surface*, p. ibid. n. 1429.
The Weight of the Moon, *p.* ibid *n.* 1429.
The Figure of the Moon, *p* 283. *n.* 1431.
A Phyſical Explanation of the Motion of the Moon, *p.* 243. *n.* 1285. and fol.
The Motion and Diſtance of the Moon (2.) *p.* 157. *n.* 967. and fol.
The Dimenſions of the Moon, *p.* 159. *n.* 977.
The Diſtance of the Moon, *if in its periodical Time it was carried round the Earth, and the Earth ſtood ſtill*, p. 228. n. 1253.
The Determination of the Forces that diſturb the Moon, *p.* 245. *n.* 1291. *p.* 247. *n.* 1296. *p.* 251. *n.* 1306, 1307. *p.* 259. *n* 1336.
The Motion of the Apſides of the Moon, *p.* 157. *n.* 970. *p.* 256. *n.* 1325.
The Motion of the Nodes of the Moon, *p.* 157. *n.* 970. *p.* 260. *n.* 1341 and fol.
The Change of the Moon's *Excentricity*, p. 157. n. 968. p. 257. n. 1328, 1329.
The Change of the Inclination of the Moon's *Orbit*, p. 157. n. 969. p. 261. n. 1345. and fol.
A Periodical Lunar Month (2) *p.* 175. *n.* 1037.
——— *Synodical* Month, *p* ibid. *n.* 1038.
——— *Body moveable or ſuſceptible of* Motion (1.) *p* 4. *n.* 11.
Motion (1) *p.* 19. *n* 47.
——— *its Quantity*, p. 20. n. 54.
——— *its Direction*, p. 21 n. 55.
——— *its Laws*, p. 49 n. 124. and fol.
The comparing of Motions (1.) *p* 22. *n.* 62. and fol.
Accelerated Motion (1) *p.* 51. *n.* 127.
Motion *retarded*, p 52. n. 128.
——— *compounded*, p. 85. n. 190. and fol.
——— ——— p. 88. n. 192.
——— *Relative* (2.) p. 161. n. 985.

Motion *Apparent*, ibid. *n.* 985. *p.* 163. *n.* 992. and fol.
——— *in Conſequentia*, p. 153. n. 946.
——— *in Antecedentia*, p. 154. n. 947.
——— *diurnal*, p. 181. n. 1074. n. 182. n. 1081. and fol.
——— *of Fluids* (1.) p. 174. n. 354. and fol.
——— *of Light*. See *Light*.
——— *its Quantity in the World not always the ſame* (1) n. 187, 188.

N.

Nadir (2.) *p.* 186. *n.* 1100.
The Nodes *of the Planets* (2.) p. 153. n. 941.
The Line of Nodes, *p.* ibid. *n.* 942.
New Moon (2.) *p.* 175, *n.* 1042.
Two Nubeculæ *in the Heavens* (2.) p. 104. n. 1201.

O.

Opaque *Body* (2.) p. 58. n. 709.
Opacity *depends upon the Pores* (2.) p. 105. n 843.
Octave (1.) *p.* 255 *n.* 527.
Oppoſition *of Cœleſtial Bodies* (2.) p. 167. n. 1011.

P.

Parallax of the Stars (2.) p. 187. n 1106. and fol.
——— *annual*, p. 282. n. 1187, 1188.
Subtility of Parts (1.) p. 9. n. 20.
Pendulum (1.) *p.* 61. *n.* 153.
——— *compound*, p. 65. n. 161.
Motions of Pendulums, *p.* 61. *n.* 154. and fol.
Penumbra (2.) *p.* 179. *n* 1060.
Percuſſion *direct* (1.) p 67. n. 166
——— *of Bodies not elaſtic*, p. 72. n. 171. and fol.
——— *of elaſtic Bodies*, p. 77. n. 179. and fol.
——— *oblique*, p. 89. n. 193. and fol.
Perihelia *of Planets*.
Natural Phænomena (1.) p. 2. n. 2.
Phoſphorus *of Urine* (2.) p. 12. n. 575.
——— *in a Vacuum* (2.) p. 18. n. 595.
Natural Philoſophy (1.) *p.* 2. *n.* 3.
Place (1.) *p.* 19. *n.* 48, 49, 50.
Plaſter *ſhines in a Vaccuum* (2.) p. 10. n. 570.
Planets (2.) *p.* 151. *n.* 926.

Planets *Primary*, p. 151. n. 927.
——*Secondary*, ibid. *n.* 928.
——*Inferior*, p. 156. n. 964.
——*Superior*, ibid.
The Appearances of Inferior Planets, *p.* 168. *n.* 1015. and fol.
The Appearances of Superior Planets, *p.* 171. *n.* 1024. and fol.
——*Their Figures determined*, p. 264. n. 1360.
——*their Diſtances*, p. 155. n. 956. and fol.
——*their Dimenſions*, p. 158. n. 975. p. 231. n. 1256.
——*their Weights*, p. *ibid.* n. 1255.
——*their Denſities*, p. *ibid.* n. 1260.
——*their Motions*, p. 151. n. 929. and fol.
——*the Effects of their mutual Actions*, p. 235. n. 1274.
——*they revolve about the Center of Gravity of the whole Syſtem*, p. 234. n. 1264.
——*their Orbits are at reſt*, ibid. *n.* 1265.
——*their Motions explained according to the Principles of Natural Philoſophy*, p. 235. n. 1275.
Motions and the Diſtances of the Secondary Planets, *p.* 156. *n.* 965. and fol. *p.* 191. *n.* 1130. and fol.
——*an Explanation of theſe Motions*, p. 240. n. 1277. and fol.
The Points *of Reſt in Strings in Motion* (1.) p. 257. *n.* 538, 539.
The Poles *of a Planet* (2.) p. 154. n. 953.
——*of the World.*
——*Arctic*, p. 184. n. 1090.
——*Antarctic*, ibid. *n.* 1091.
——*of the Ecliptic*, p. 166. n. 1007.
The Polar *Circles*, p. 184. n. 1091. p. 188. n. 1114.
Power (1.) *p.* 21. *n.* 56.
——*its Intenſity*, p. 21. n. 57.
The Actions of Powers *compared*, p. 24. n. 67. and fol.
The Actions of oblique Powers *determined*, p. 91. n. 196. and fol.
The Præceſſion *of the Æquinoxes.* See *Æquinox.*

The

The Projection *of heavy Bodies* (1.) p. 99. n. 208. and fol.
Pulley (1.) *p.* 27. *n* 82, 83. *p.* 40. *n.* 115. and fol.
Common Pumps (1.) *p.* 236. *n.* 472.

R.

Radiant *Point* (2.) p. 40. n. 645.
Rainbow. *See* Iris.
Ray *of Light* (2.) p. 23. n. 610.
——— *diverging* (2.) p. 39. n. 643.
——— *converging*, p. 40. n. 648.
——— *incident*, p. 28. n. 620.
——— *refracted*, ibid. *n.* 620.
——— *reflected*, p. 81. n. 780.
——— *homogeneous*, p. 108. n. 849.
——— *heterogeneous*, ibid. *n.* 850.
——— *they move in Curve Lines in the Air*, p. 178. n 1056.
Reflexion *of Light from Bodies* (2.) p. 58. n. 710.
——— *from a poliſh'd Surface* (2.) p. 81. n. 779.
——— *its Laws*, ibid. *n.* 783. and fol.
——— *it has a great Relation with Refraction*, p. 86. n. 795. and fol.
Black Bodies reflect *no Light*, p. 107. n. 845.
Refraction *of Light* (2.) p. 26. n. 616.
——— *when cauſed*, ibid. *n.* 617.
——— *whence it ariſes*, ibid. *n.* 618.
——— *its Laws*, p. 28. n. 624. and fol.
A conſtant Proportion between the Sine of Incidence and the Sine of Refraction, *p.* 37. *n.* 639.
The Cauſe of this Effect, p. 31. n. 633. and fol.
The Laws of Refraction *in Mediums divided by the plane Surface*, p. 39. n. 643. *in Mediums divided by a ſpherical Surface*, p. 44. n. 660.
Refraction *of the Stars*, p. 188. n. 1110. and fol.
Refrangibility *different in different Rays* (2.) p. 108. n. 847.
——— *conſtantly the ſame in ſingle Rays*, p. 115. n. 855.
——— *the greater it is, the more eaſily are Rays reflected*, p. 122. n. 868.

Repul-

Repulſion (1.) *p.* 15. *n.* 40. and fol.
Reſiſtance *of Fluids* (1.) p. 162. n. 319. and fol.
Retardation *of Bodies aſcending vertically* (1.) p. 55. n. 135.
——*Aſcending upon an inclined Plane*, p. 60. n. 151. and fol.
——*of Bodies moving in Fluids* (1.) p. 165. n. 329.
Retardation *of a Pendulum in a Fluid*, p. 171. n. 347. and fol.
——*of a Body riſing upwards*, p. 172. n. 351. and fol.
Retardations *compared with one another*, p. 165. n. 331. and fol.
——*compared with Gravity*, p. 166. n. 336.
Ring *of Saturn* (2.) p. 156. n. 963. p. 174. n. 1034.
Riſing *of the Stars* (2.) p. 186. n. 1097.
River (1.) *p.* 195. *n.* 390.
——*its Section*, p. 195. n. 391.
——*its Courſe*, p. 195. n. 392. and fol.
Rules *for reaſoning in Philoſophy* (1.) p. 3. *n.* 5, 6, 7.

S.

Satellites. See *Secondary Planets.*
Saturn (2.) *p.* 156. *n.* 963.
——*its Weight*, p. 231. n. 1255.
——*Gravity on its Surface*, p. ibid. n. 1258.
——*its Denſity*, p. ibid. n. 2260.
——*the Force with which it acts on Jupiter*, p. 238. n. 1272.
An inſide Screw (2.) p. 45. n. 121.
An outſide Screw, *ibid.*
The uſe of both, ibid.
An endleſs Screw (1.) *p.* 47. *n.* 123.
Seaſons *of the Year*, p. 199. n. 1176. and fol.
Sky-Rocket, *p.* 22. *n.* 609.
——*in the torrid Zone*, p. ibid. n. 1179. and fol.
Seſquiditonus (1.) *p.* 255. *n.* 531.
The Setting *of the Stars* (2.) p. 183. n. 1089.
Signs *of the Zodiac.* See *Zodiac.*
Smoak (2.) *p.* 15. *n.* 587. *p.* 17. *n.* 592.
Soft *Body* (1.) p. 11. n. 29.

The

The Sun *agitated by a ſmall Motion* (2.) p. 155. n. 957. p. 235. n. 1266.
——*the Effects of its Motion*, p. 235. n. 1267.
——*turns round its Axis*, p. 155. n. 957. p. 180. n. 1071.
——*ſeems to be moved by the Motion of the Earth*, p. 164. n. 996. and fol.
——*why it appears larger near the Horizon*, p. 67. n. 735.
Eclipſe of the Sun, *p.* 176. *n.* 1046.
——*different in different Places*, p. 179. n. 1065.
——*when it happens*, p. 118. n. 1059.
——*partial*, p. 180. n. 1067, 1068.
——*total*, p. 179. n. 1067, 1068.
——*central*, p. 180. n. 1068.
——*annular*, ibid. 1070.
The Weight of the Sun, p. 231. n. 1255.
——*Gravity on its Surface*, p. *ibid.* n. 1258.
——*its Denſity*, p. *ibid.* n. 1260.
Solidity *of Matter* (1.) p. 4. n. 9.
Solſtices (1.) p. 195. n. 1155.
Sound *depends upon the Air* (1.) p. 249. n. 504.
——*its Intenſity*, p. 253. n. 515. and fol.
——*it is augmented in Air compreſſed*, p. 253. n. 516.
—— *its Celerity*, p. 251. n. 508. and fol.
Space. See *Vacuum*.
Sphere, *parallel* (2.) p. 190. n. 1123, 1124.
——*oblique*, p. ibid. n. 1125. and fol.
——*right*, p. 192. n. 1138. and fol.
——*fix'd* Stars (2.) *p.* 150. *n.* 923. *p.* 202. *n.* 1190. and fol.
——*found to be very numerous by the Help of Teleſcopes*, p. 204. n. 1202.
——*ſome of them periodical*, p. 204. n. 1203.
——*ſome of them have appeared, and then totally diſappeared*, p. *ibid.* n. 1204.
White Spots *in the Heavens* (2.) p. 204. n. 1205.
The Conſonances of Strings (1.) *p.* 256. *n.* 532. and fol.

The

The Motion of ſome Strings *communicated to others*, p. 256. n. 536. and fol.
Syphon (1.) *p.* 233. *n.* 467, 469. *p.* 234. *n.* 470.
Points of Suſpenſion (1.) *p.* 28. *n.* 86.
Planetary Syſtem (2.) *p.* 150. *n.* 922.
——— *an Explanation of it according to the Principles of Natural Philoſophy* (2.) p. 235. n. 1275.
Syzygies (2.) *p.* 276. *n.* 1044.

T.

Teleſcope (2.) p. 76. n. 768.
——— *Aſtronomical*, ibid. *n.* 769.
——— *proper to view terreſtrial Objects*, p. 77. n. 772. p. 77. n. 776.
——— *why they are not more perfect*, p. 122. n. 867.
Thermometer (2.) *p.* 19. *n.* 598, 599.
Natural Things (1.) *p.* 1. *n.* 1.
Tide (2.) p. 274. n. 1395. and fol.
——— *derived from the Influence of the Sun and Moon*, p. 273. n. 1390. and fol.
The Forces of Influences determined, p. 273. n. 1416. and f.
Time (1.) *p.* 20. *n.* 51, 52.
Mean Time (2.) *p.* 194. *n.* 1145.
Tone (1.) *p.* 255. *n.* 522.
——— *grave*, ibid.
——— *acute*, ibid.
Tropics (2.) *p.* 183. *n.* 1089. *p.* 188. *n.* 1114.
Tubes *filled with Gun-powder* (2.) p. 22. n. 609.
Tranſparent *Body* (2.) p. 104. n. 840.
The Parts of all Bodies tranſparent, *ibid.* n. 841.
Tranſparent *Bodies become opaque upon the Separation of their Parts*, p. 106. n. 844.
Speaking Trumpet (1.) *p.* 258. *n.* 543.
Twilights (2.) *p.* 194. *n.* 1149. and fol.

V.

A Vacuum *is poſſible* (1.) p. 5. n. 13.
——— *its Properties* (1.) p. 7. n. 15.
——— *its real Exiſtence in Nature* (2.) p. 217. n. 1239. and fol.

Velo-

Velocity (1.) *p.* 20. *n.* 53.
Venus (2.) *p.* 155. *n.* 959.
——*it is an Aſſemblage of Stars*, p. 204. n. 1200.
Vibrations *of Pendulums.* See *Pendulums.*
——*of Fibres.* See *Fibres.*
Viſion (2.) *p.* 62. *n.* 716.
Diſtinct Viſion, *p.* 63. *n.* 717. *p.* 64. *n.* 724. *p.* 65. *n.* 728.
Confuſed Viſion, *p.* 63. *n.* 718.
Judgment concerning the Diſtance of Objects ſeen, p. 66. n. 729. and fol.
Apparent Magnitude, p. 66. n. 733.
Judgment concerning the Magnitude, ibid. *n.* 734.
Viſion *through a plane Glaſs* (2.) p. 68. n. 739. and fol.
——*through a convex Lens* (2.) p. 69. n. 745. and fol.
—— *through a concave Lens* (2.) p. 72. n. 757.
——*Objects appear magnified in Water* (2.) p. 69. n. 744.

W.

Wave *on the Surface of a Fluid* (1.) p. 201. n. 402. p. 202. n. 405.
——*Breadth of it*, p. 202. n. 404.
——*Motion and Reflexion of it*, &c. *p.* 201. *n.* 402. *p.* 202. *n.* 405.
——*Celerity of them*, p. 208. n. 416.
Wave *in Air*, p. 239. n. 476.
——*Motion of them and Celerity*, &c. p. 240. n. 477. and fol.
Water *and melted Ice* (2.) p. 20. n. 604.
Wedge (1.) *p.* 43. *n.* 118, 119.
Point of the Weſt (2.) p. 187. n. 1103.
Wheels *with Teeth* (1.) p. 39. n. 114.
Whiteneſs (2.) *p.* 124. *n.* 870.
——*reſulting from a Mixture of Colours*, ibid. *n.* 871, *and* 872.
A white Body *grows warm ſooner than other coloured Bodies*, p. 145. n. 909.
Shining Wood (2.) *p.* 13. *n.* 578.

Ze-

Z.

Zenith (2.) *p.* 186. *n.* 1099.
Zodiac (2.) *p.* 166. *n.* 1008, 1009.
——*its Signs*, p. 165. n. 999. p. 202. n. 1191, 1192.
Zones (2.) *p.* 196. *n.* 1159. and fol.
——*Phænomena of the Frigid* Zones, *p.* 196. *n.* 1165. *p.* 197. 1170. and fol. *p.* 199. n. 1176. and fol.
——*of the Temperate ones*, p. 196. n. 1165. and fol. *p.* 199. *n.* 1176. and fol.
——*Torrid* Zones, *p.* 196. *n.* 1163, 1167. *p.* 199. *n.* 1179. and fol.

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